VOLUME 23 JUNE, 1935 NUMBER 6

PROCEEDINGS
of
The Institute of Radio Engineers

Tenth Annual Convention

Detroit, Michigan
July 1, 2, and 3, 1935

Application Blank for Associate Membership on Page XIII

INSTITUTE OF RADIO ENGINEERS
TENTH ANNUAL CONVENTION
HOTEL STATLER, DETROIT MICHIGAN
JULY 1, 2, AND 3, 1935

CONDENSED PROGRAM

Sunday—June 30

4:00 P.M.–6:00 P.M. Registration

Monday—July 1

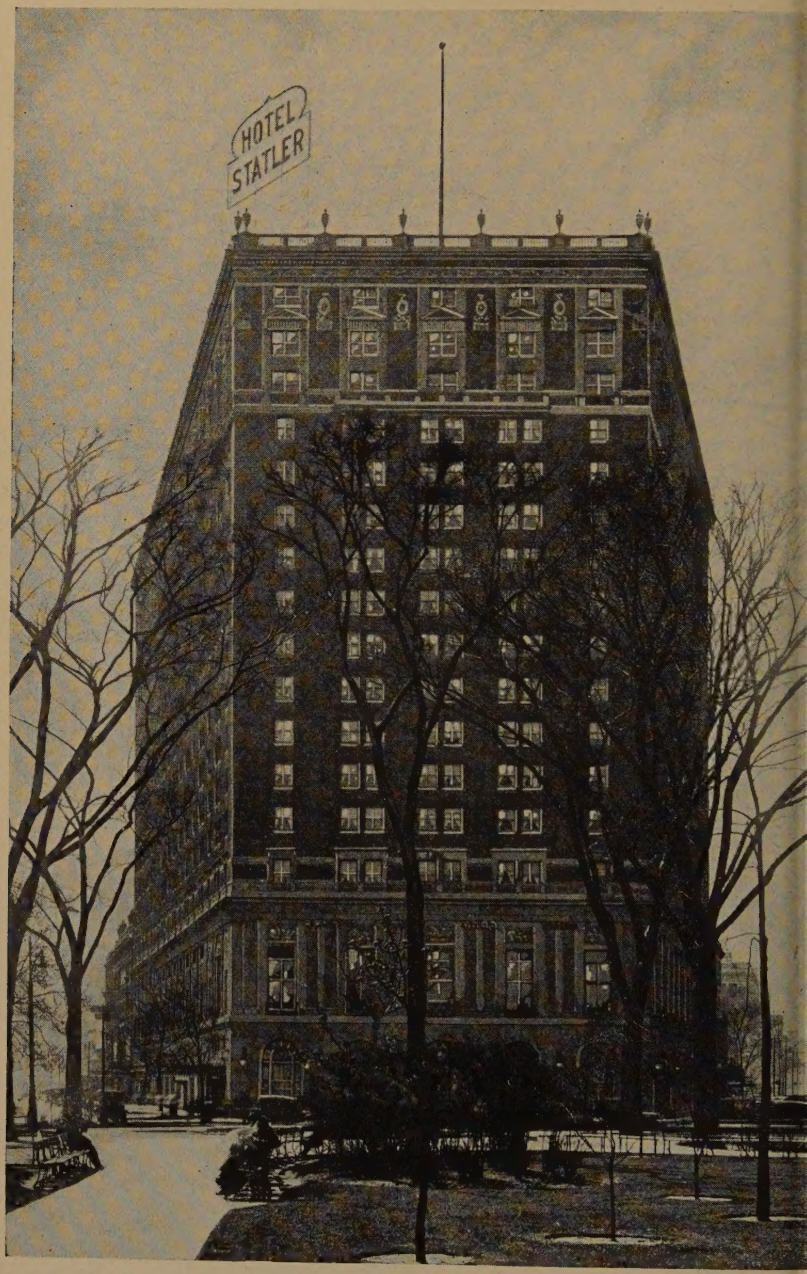
9:00 A.M. Registration and opening of exhibition.
10:00 A.M.–12:30 P.M. Official welcome and technical session—Large Meeting Room.
10:00 A.M.–11:00 A.M. Official greetings at ladies headquarters.
11:00 A.M.–5:00 P.M. Trip No. 1. Ladies sight-seeing trip.
12:30 P.M.–2:00 P.M. Luncheon and inspection of exhibits.
2:00 P.M.–3:30 P.M. Technical Session—Large Meeting Room.
2:00 P.M.–3:30 P.M. Technical Session—Small Meeting Room.
3:30 P.M.–6:00 P.M. Trip No. 2. General Motors Research Laboratory.
6:00 P.M.–7:00 P.M. Inspection of exhibits.

Tuesday—July 2

9:00 A.M.–10:00 A.M. Registration and inspection of exhibits.
10:00 A.M.–11:30 A.M. Technical Session—Large Meeting Room.
10:00 A.M.–11:30 A.M. Technical Session—Small Meeting Room.
10:00 A.M.–11:30 A.M. Trip No 3. Ladies shopping tour.
11:30 A.M.–6:00 P.M. Trip No. 4. Greenfield Village.
6:00 P.M. Exhibits close.
7:00 P.M. Annual banquet and entertainment.

Wednesday—July 3

9:00 A.M. Registration and opening of exhibits.
10:00 A.M.–11:30 AM.. Technical Session—Large Meeting Room.
10:00 A.M.–11:30 A.M. Technical Session—Small Meeting Room.
11:00 A.M.–6:00 P.M. Trip No. 5. Ladies luncheon and sight-seeing trip.
11:30 A.M.–1:00 P.M. Luncheon and inspection of exhibits.
1:00 P.M.–6:00 P.M. Trip No. 6. Ford Motor Plant.
4:00 P.M. Closing of exhibits.



Convention Headquarters. Hotel Statler, Detroit, Michigan

INSTITUTE NEWS AND RADIO NOTES

Tenth Annual Convention

The Board of Directors of the Institute accepted an invitation tended by the Detroit Section to hold our Tenth Annual Convention that city. The dates set for this meeting are July 1, 2, and 3 and the adquarters will be located at the Hotel Statler. The various tech-cal sessions and banquet will be held in the hotel and a number of teresting inspection trips for both the ladies and men have been ranged.

The number of papers submitted for presentation and the time quired for them are such as to make necessary the holding of two chnical sessions simultaneously. While it is impossible to arrange esentations so no one will be compelled to miss a paper in which he interested, it is hoped that such probabilities have been reduced to minimum. At each session, the paper which is being presented at the her session will be announced and it will be permissible for those terested to leave or enter a meeting at any time.

The following program is practically complete and it is expected at relatively few changes will be made in it. Such changes as may be cessary will probably be of minor nature.

SUNDAY, JUNE 30

:00 P.M.-6:00 P.M. Registration

MONDAY, JULY 1

:00 A.M. Registration and opening of exhibition.

:00 A.M.–12:30 P.M. Official welcome and technical session. Addresses of welcome by Stuart Ballantine, President of the Institute; and H. L. Byerlay, Chairman of the Convention Committee.

Technical Session—Large Meeting Room

"Electron Beams and Their Application in Low Voltage Devices," by H. C. Thompson, RCA Radiotron Division, RCA Manufacturing Company, Harrison, N.J.

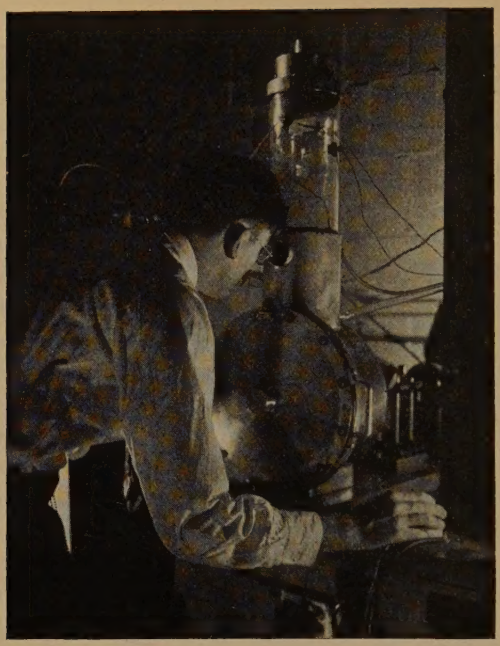
"Frequency Control by Low Power Factor Line Circuits," by C. W. Hansell, F. H. Kroger, and P. S. Carter, RCA Communications, New York, N.Y.

"Design and Equipment of a 50-kilowatt Broadcast Station for WOR," by J. R. Poppele, Station WOR, Newark, N.J.; and F. W. Cunningham and A. W. Kishpaugh, Bell Telephone Laboratories, New York City.

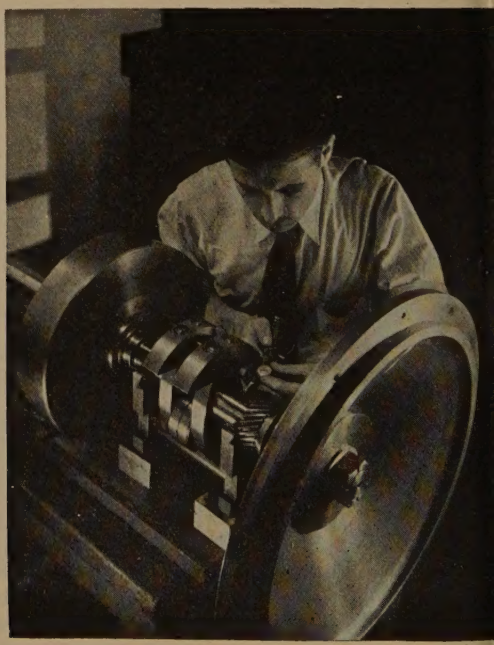
00 A.M.–11:00 A.M. Official greetings at ladies headquarters.

00 A.M.–5:00 P.M. Trip No. 1. Ladies sight-seeing trip.

30 P.M.–2:00 P.M. Luncheon and inspection of exhibits.



Using cathode rays to measure ignition efficiency
at General Motors Research Laboratories



Making precision micrometric measurements bef
spectrographic analysis at General Motors

2:00 P.M.–3:30 P.M. **Technical Session—Large Meeting Room**

"Automatic Selectivity Control," by G. L. Beers, RCA Victor Division, RCA Manufacturing Company, Camden, N.J.

"Automatic Frequency Control," by Charles Travis, RCA License Laboratory, New York City.

"Panel Lamps and Their Characteristics," by J. H. Kurlander, Westinghouse Lamp Company, Bloomfield, N.J.

2:00 P.M.–3:30 P.M. **Technical Session—Small Meeting Room**

"Magnetron Oscillators for Generating Frequencies from 300 to 600 Megacycles," by G. R. Kilgore, RCA Radiotron Division, RCA Manufacturing Company, Harrison, N.J.

"An Unattended Ultra-Short-Wave Radiotelephone System," by N. F. Schlaack and F. A. Polkinghorn, Bell Telephone Laboratories, New York City.

"Some Notes on Piezo-Electric Crystals," by Issac Koga, Tokyo University of Engineering, Tokyo, Japan.

3:30 P.M.–6:00 P.M. Trip No. 2. General Motors Research Laboratory

6:00 P.M.–7:00 P.M. Inspection of exhibits.

TUESDAY, JULY 2

9:00 A.M. Registration and opening of exhibition.

0:00 A.M.–11:30 A.M. **Technical Session—Large Meeting Room**

"Recent Developments of Class B Audio- and Radio-Frequency Amplifiers," by L. E. Barton, RCA Victor Division, RCA Manufacturing Company, Camden, N.J.

"General Theory and Application of Dynamic Coupling and Power Tube Design," by C. F. Stromeyer, Revelation Patents Holding Company, New York City.

"Notes on Intermediate-Frequency Transformer Design," by F. W. Scheer, S. W. Sickles Coil Company, Springfield, Mass.

0:00 A.M.–11:30 A.M. **Technical Session—Small Meeting Room**

"Some Theoretical Considerations Relating to Vacuum Tube Design," by G. D. O'Neill, Hygrade Sylvania Corporation, Salem, Mass.

"Ratings and Operating Information on Large High Vacuum Tubes," by R. W. Larson, General Electric Company, Schenectady, N. Y., and E. E. Spitzer, RCA Radiotron Division, RCA Manufacturing Company, Harrison, N.J.

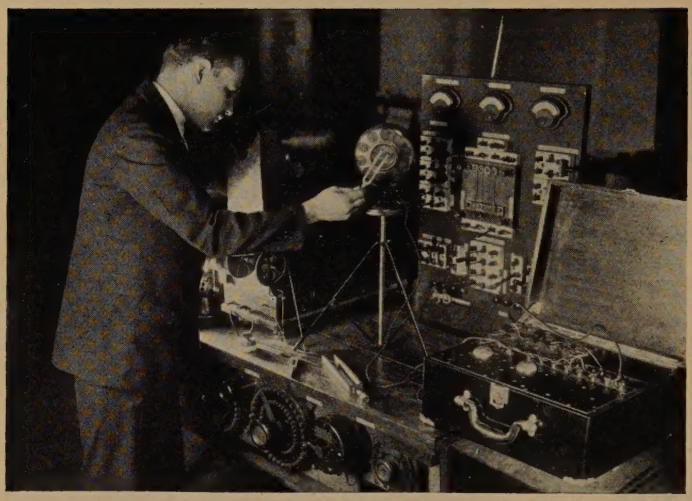
"Analysis of the Operation of Vacuum Tubes as Class C Amplifiers," by I. E. Mouromtseff and H. N. Kozanowski, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

0:00 A.M.–11:30 A.M. Trip No. 3. Ladies Shopping Tour.

:30 A.M.–6:00 P.M. Trip No. 4. Greenfield Village.

:00 P.M. Exhibits close.

:00 P.M. Annual Banquet and entertainment. Main Banquet Room.



Radio types of equipment for the measurement and analysis of noises encountered in automobiles used by General Motors

Spectroscopic analyses of metals are made at General Motors to detect even minute quantities of impurities

WEDNESDAY, JULY 3

9:00 A.M. Registration and opening of exhibition.

10:00 A.M.–11:30 A.M. **Technical Session—Large Meeting Room**

"A New Tube for Use in Superheterodyne Frequency Conversion Systems," by C. F. Nesslage, E. W. Herold, and W. A. Harris, RCA Radiotron Division, RCA Manufacturing Company, Harrison, N.J.

"A New Type of Gas-Filled Amplifier Tube," by J. D. LeVan and P. T. Weeks, Raytheon Production Corporation, Newton, Mass.

10:00 A.M.–11:30 A.M. **Technical Session—Small Meeting Room.**

"Ultra-Short-Wave Propagation Over Land," by C. R. Burrows, Alfred Decino, and L. E. Hunt, Bell Telephone Laboratories, New York City.

"A Note on the Source of Interstellar Interference," by K. G. Jansky, Bell Telephone Laboratories, New York City.

"Comparison of Cosmic Data with Characteristics of the Ionosphere at Washington," by E. B. Judson, National Bureau of Standards, Washington, D.C.

"A Study of Radio Field Intensity Versus Distance Characteristics of a High Vertical Radiator at 1080 Kilocycles," by S. S. Kirby, National Bureau of Standards, Washington, D.C.

11:00 A.M.–6:00 P.M. Trip No. 5. Ladies luncheon and sight-seeing trip.

11:30 A.M.–1:00 P.M. Luncheon and inspection of exhibits.

1:00 P.M.–6:00 P.M. Trip No. 6. Ford Motor Plant.

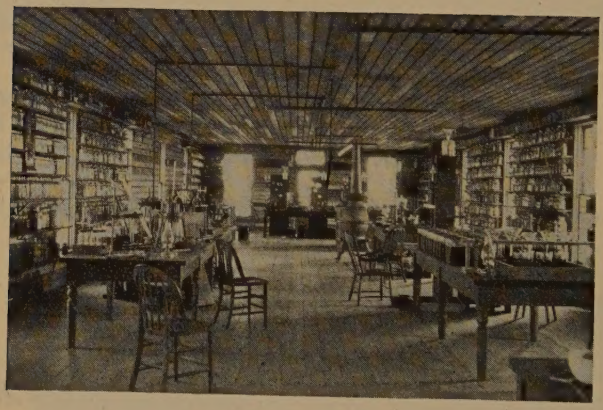
4:00 P.M. Closing of exhibits.

Technical Sessions

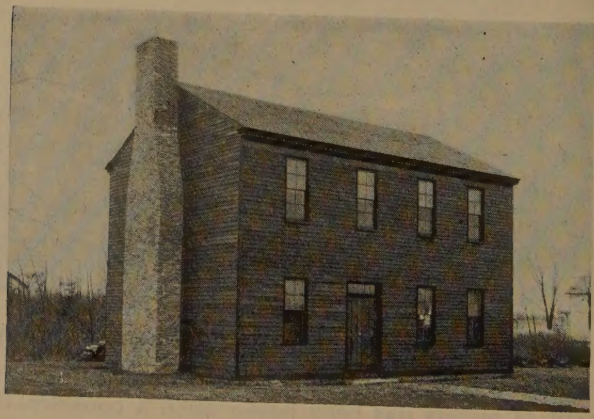
In accordance with the policy followed during the last two conventions, none of the papers presented will be available in preprint form. This has made necessary the allotment of sufficient time for the presentation of each paper in sufficient detail to permit a reasonable discussion of its contents. Inasmuch as the presentation of a paper is justified only if a valuable discussion ensues, those interested in the subjects treated are urged to be present and participate actively in the consideration given each paper. Time has been allowed for such discussion at each technical session. Because of the number of papers to be presented and the time required for the presentation of each, it is absolutely essential that all technical sessions start promptly on time.

It has been necessary to schedule two sessions of technical papers for each period available for that purpose with the exception of the opening session on Monday morning. As far as possible, the arrangement of papers has been based upon a consideration of the probable

Dearborn Inn



Edison Laboratory



Lincoln Court House

groups interested in them. It is believed that conflict in group interests has been reduced to a minimum. Arrangements have been made to keep those at a given technical session in contact with the papers that are being presented at the other session. It will be possible to move freely from one meeting room to the other during technical sessions. Summaries of papers to be presented will be found at the end of this announcement and are arranged alphabetically by the names of the authors.

Inspection Trips

Monday, July 1—Trip No. 1

Ladies Sight-Seeing Trip

Busses will leave the hotel promptly at 11:00 A.M. when a visit will be made to Belle Isle, an island park of almost a thousand acres of natural beauty. In its zoo will be found sacred cows from India and the aquarium and horticultural hall will be visited. From the Isle the busses will pass the Hudson Motor Car Company and one of the Chrysler factories. They will proceed through Grosse Pointe and the fashionable residential section of Detroit as far as the Edsel Ford home and back to the Grosse Point Yacht Club for a luncheon-bridge and fashion show.

Trip No. 2

General Motors Research Laboratories

Departure from the hotel will be made for the General Motors Research Laboratories at 3:30 P.M. In this laboratory the research program of the General Motors Corporation centers and it is devoted to development work on chemical, physical, and electrical problems involved in the design and manufacture of the modern automobile.

Tuesday, July 2

Trip No. 3

Ladies Shopping Tour

The ladies will leave the hotel at 10:00 A.M. for the J. L. Hudson and Company department store which is Detroit's leading establishment of this type. Organized tours of the store will be made.

Trip No. 4

Greenfield Village

The entire afternoon will be devoted to this visit to Greenfield Village. Busses will leave the hotel at 11:30 A.M. and will arrive at the

Entrance to Greenfield Village

Detroit News

Grosse Pointe Yacht Club

Botsford Inn

Dearborn Inn where lunch may be obtained. Greenfield Village which ras founded by Henry Ford, centers on the "green" like all colonial ommunities. Our visit will take us to Edison's Laboratory, Clinton nn, and several other buildings famous in American history. The vil-ge portrays early colonial life and in it are found among other struc-ures old schools, a church, a tintype makers shop, the apothecary store nd post office, the grocery and drygoods store, and the old Lincoln ourthouse.

The Edison Institute Museum is entered through a replica of ndependence Hall and is devoted to exhibits of early American arts nd sciences. The electrical exhibition includes almost every type of lectrical device developed and includes sections of every telegraph able laid across the Atlantic Ocean.

Wednesday, July 3

Trip No. 5

Ladies Luncheon and Sight-Seeing Trip

At 11:30 A.M., busses will leave the hotel for Botsford Inn. About ne hundred years old, it has been reconditioned by Mr. Ford and rnished in its original style. Luncheon will be served at the Inn and ne trip will continue to the Cranbrook Educational Institutions, which clude schools from elementary grades through college preparatory ork for both boys and girls. Christ Church with the largest and most mplete set of chimes in this country will be visited as will the Cran-rook Institute of Science and the Cranbrook Academy of Art. From ranbrook we visit the radio-famous Shrine of the Little Flower. he next stop is at the Detroit zoo where wild animals are found in eir native settings, there being no fences between them and the sitors.

Trip No. 6

Ford Motor Plant

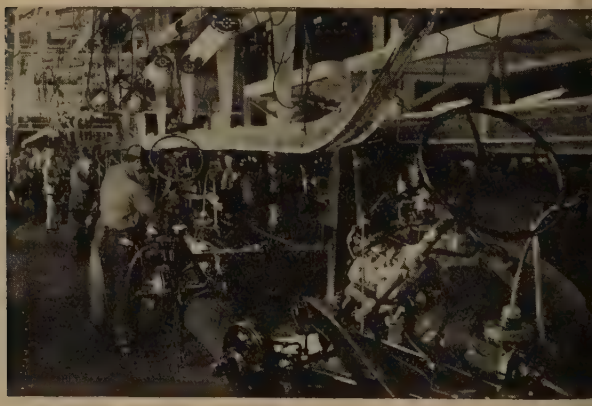
At 1:00 P.M. busses will leave for the Ford Motor plant and the ternoon will be devoted to an inspection tour of it. This is the largest ngle industrial unit in the world and covers over a thousand acres. here are almost a hundred miles of railroad track within its bounda-es and eighty thousand men are employed in its operation. It includes ast furnaces, a steel mill, glass plant, the world's largest foundry, d over seven million square feet of floor space.

Exhibition

Our annual exhibition of component parts, manufacturing aids, and easuring devices will be held this year as in the past. The exhibitions

Where Ford cars are put together

Aerial view of the Ford plant



Another view of the Ford assembly line

ill be arranged in booths distributed about a large central room rough which everyone will pass in going to the technical sessions. ooths will be in charge of men competent to discuss the engineering pects of the products on display and this offers an excellent opportnity for engineers to become acquainted with recent developments the radio field.

Banquet

The annual banquet will be held on Tuesday evening at seven clock. The two annual Institute awards will be presented to their cipients during the banquet. The Medal of Honor will be bestowed on Balth. van der Pol, Jr. and the Morris Liebmann Memorial rize given to F. B. Llewellyn.

Reduced Railroad Rates

Reduced rates on the certificate plan have been granted by the ilroads. It is necessary when purchasing your ticket to Detroit to quest a certificate for this convention. If more than one hundred of ese certificates are presented at the convention, they will be validated and will permit the holder to purchase a return trip ticket over e same route as traveled to the convention at one third of the regular ilroad fare. Everyone traveling to the convention by rail is urged obtain a certificate even though the saving in a particular case may small. It is necessary that at least one hundred certificates be obined and your certificate may assist someone in obtaining a substantial reduction on the railroad fare from a distant point.

Sections Committee Meeting

The annual meeting of the Sections Committee will be held in the enry II room on the convention floor of the hotel at 6:00 P.M. on onday, July 1. Representatives of each Institute section should be resent at this meeting which will be devoted to a discussion of Institute policies concerning the operation of all sections. The chairman or cretary of each section is a logical representative but if neither of ese can be in attendance, the duty may be delegated to some member the section who will be able to attend this meeting.

SUMMARIES OF TECHNICAL PAPERS

RECENT DEVELOPMENTS OF CLASS B AUDIO- AND RADIO-FREQUENCY AMPLIFIERS

L. E. Barton

(RCA Victor Division, RCA Manufacturing Company, Camden, N.J.)

Class B audio-frequency and radio-frequency amplifiers have many applicans but may be the source of considerable distortion unless the necessary pre-

cautions are taken to prevent nonlinearity of such amplifiers. Undoubtedly, most important factor in the design of a class B amplifier for low distortion is characteristic of the driver system. Tube characteristics and the use of a pr load are also important but are more definite and more generally understood.

The purpose of this paper is to present the results of recent development the class B audio and radio amplifiers. The results of the investigations indi that a heavily loaded driver system in general is undesirable because of the po consumed and because such loading results in greater distortion than obtain by other means.

The general procedure adopted to reduce distortion was to prevent dis tion in each unit of the amplifier system. Distortion balancing schemes are only critical to adjust but are likely to introduce higher order harmonics w may be more objectionable than a higher measured value of a lower order monic. Actual performance data are presented for medium and relatively powered audio and radio systems. The necessary input requirements to pe the performance obtained are discussed.

Sufficient theory is given to make the paper complete and to show that actual performance of such amplifiers can be quite accurately predicted if necessary tube characteristics are known.

AUTOMATIC SELECTIVITY CONTROL

G. L. Beers
(RCA Victor Division, RCA Manufacturing Company, Camden, N.J.)

A receiving system is described in which the selectivity automatically v with the sensitivity. The variation in selectivity is obtained through the u several triodes whose plate-to-cathode impedance is shunted across a numb the receiver tuned circuits. The circuits with which these selectivitity co tubes are associated are described. Circuit diagrams illustrate the metho which the control-grid potentials of the automatic selectivity control tube caused to vary with the strength of received signals. A manual control i scribed which permits the user to increase the selectivity over that determ by the strength of the received signal. Curves are given showing the chan over-all selectivity with sensitivity, the relation between fidelity and sensiti and distortion as a function of power ouput.

ULTRA-SHORT-WAVE PROPAGATION OVER LAND

C. R. Burrows, Alfred Decino, and L. E. Hunt
(Bell Telephone Laboratories, New York City)

From theoretical considerations it is found that for ultra-short-wave p gation over level terrain, the received field should equal 4π times the pro of the antenna heights divided by the product of the wavelength and the tance times the field that would be received for transmission in free space.

This equation has been checked experimentally for horizontal polariza antenna heights between two and 25 meters and frequencies between 17 an megacycles for the two distances 9.4 and 26.3 kilometers. The results ind that in the absence of detailed information regarding the transmission path formula gives the probable value of the received field. The deviations actual path from the ideal should cause corresponding deviations in the rec field from that calculated by the above formula. For these two paths, the of the deviations was found to be about three or four decibels.

At 45 kilometers fading was observed with low antennas, and at greater distances there were rather large variations in the received field at all antenna heights available.

At higher frequencies and longer distances the curvature of the earth introduces additional attentuation. At the distance $d = 5 \times 10^4 k^{2/3} \lambda^{1/3}$ meters theoretical considerations indicate that the curvature of the earth will reduce the field strength by a factor of about 2, and beyond this "shadow distance" by the factor $2ka/\pi\sqrt{d^3/\lambda}$, where ka is the effective radius of the earth with refraction and λ is the wavelength all measured in meters. This results in the received field being inversely proportion to the seven-halves power of the distance.

The method of calculating the received field in hilly country, which was developed on a theoretical basis in an earlier paper, has been confirmed experimentally both for an optical path and for a nonoptical path in the frequency range from 17 to about 100 megacycles. The discrepancies between the experimental and theoretical frequency characteristics between 100 and 200 megacycles indicate that some element of the phenomenon of ultra-short-wave propagation that has been omitted from the theoretical formula becomes important in this frequency range.

In these experiments it was found that comparatively small sloping areas of ground near the terminals reflected an appreciable fraction of the incident wave.

FREQUENCY CONTROL BY LOW POWER FACTOR LINE CIRCUITS

C. W. Hansell, F. H. Kroger, and P. S. Carter
(RCA Communications, New York, N.Y.)

The advantages of low power factor line circuits for controlling transmitters at very high radio frequencies are pointed out. The laws governing the design and performance of lines used as low power factor circuits have been worked out and applied to the design of lines for stabilizing the frequency of a number of transmitters ranging in frequency from about 13,000 to 500,000 kilocycles.

The frequency stability of these transmitters indicate that the line control will provide a frequency stabilizing device for use above about 20,000 kilocycles of as great practical value as piezo-electric crystals have been for use at lower frequencies.

Tests have been made which indicate that lines with substantially uniformly distributed inductance and capacity have a temperature coefficient of frequency corresponding closely to the linear coefficient of thermal expansion for the material of which the line is made. Several methods have been worked out for reducing the effect of temperature variation upon the frequency.

A NOTE ON THE SOURCE OF INTERSTELLAR INTERFERENCE

Karl G. Jansky
(Bell Telephone Laboratories, New York City)

Further consideration of the data obtained during observations on interstellar interference has shown that these radiations are received any time the antenna system is directed towards some part of the Milky Way system, the greatest response being obtained when the antenna points towards the center of the system. This fact leads to the conclusion that the source of these radiations is located in the stars themselves or in the interstellar matter distributed throughout the Milky Way.

Because of the similarity in the sound produced in the receiver headset, it i suggested these radiations might be due to the thermal agitation of charge particles.

COMPARISON OF COSMIC DATA WITH CHARACTERISTICS OF THE IONOSPHERE AT WASHINGTON

E. B. Judson
(National Bureau of Standards, Washington, D.C.)

Ionosphere observations made at the National Bureau of Standards, over period of several years are compared with cosmic data. Critical frequencies o the three major layers, together with their virtual heights, are especially studie in connection with magnetic activity. Annual results are shown, compared wit sunspots. Seasonal variations of critical frequencies and virtual heights are als shown. Sporadic E layer, appearing after the normal E-layer critical frequenc has passed, is compared with the occurrence of local and distant thunderstorm as well as cosmic data. Results of ionosphere observations at Washington durin the February 3, 1935, eclipse are discussed.

MAGNETRON OSCILLATORS FOR GENERATING FREQUENCIES FROM 300 TO 600 MEGACYCLES

G. R. Kilgore
(RCA Radiotron Division, RCA Manufacturing Company, Harrison, N.J.)

The importance of the 300- to 600-megacycle range is emphasized and th place of the magnetron oscillator in this field is pointed out.

Static characteristics of a split-anode magnetron are used to explain th operation of the negative-resistance magnetron oscillator.

Problems in the generation of large output power at very short waves a listed and methods of improving the efficiency and power output are discussed.

Several typical magnetrons are described which are capable of delivering 5 to 100 watts output at frequencies of 300 to 600 megacycles.

A STUDY OF RADIO FIELD INTENSITY VERSUS DISTANCE CHARACTERISTICS OF A HIGH VERTICAL RADIATOR AT 1080 KILOCYCLES

S. S. Kirby
(National Bureau of Standards, Washington, D.C.)

The field intensities of radio station WBT, Charlotte, N.C., were record by means of automatic recorders at seven different distances from about 70 870 kilometers (45 to 450 miles), before and after the installation of a high vert cal radiator. The records at the two nearer recording stations within 100 kil meters show that the field intensity of the ground wave was increased and th fading decreased appreciably, by the change from a T antenna to the vertic antenna. At greater distances the effects were more complex. The field intensiti and fading at all seven distances are compared for the two antenna condition The field intensity versus distance characteristics are shown for both day a night. The maximum night sky-wave intensity was received at a distance about 550 kilometers. The effect of changes in the structure of the vertical rad ator to increase its top capacity are discussed. The work was done in coöperati with the Columbia Broadcasting System, and with the assistance of a number university and other laboratories.

SOME NOTES ON PIEZO-ELECTRIC CRYSTALS

ISSAC KOGA
(Tokyo University of Engineering, Tokyo, Japan)

The structure of quartz crystals is described and the chief characteristics of plates cut at various angles to the crystal axes are given with particular attention to the effect of temperature on frequency of oscillation. Methods of reducing these temperature effects lead to the manufacture of zero temperature coefficient plates. Their application to existing transmitters previously employing X-cut plates is described.

RADIO PANEL LAMPS AND THEIR CHARACTERISTICS

J. H. KURLANDER
(Westinghouse Lamp Company, Bloomfield, N.J.)

Radio panel lamps were first used as a convenience in reading dial settings when the room illumination was inadequate for this purpose. Opaque dials, whose surface was illuminated by allowing the lamp to shine directly upon the surface of the dial, were subsequently displaced by translucent dials illuminated from the rear. The use of a translucent dial made it necessary to pay more attention to the design of the panel lamp in order to avoid shadows and uneven illumination.

The simple considerations of dial illumination were considerably complicated by the development of resonance tuning meters of the shadow producing type. These required a lamp with accurate optical characteristics which presented no small problem due to the use of automatic machinery in manufacture. Improvements in design eventually resulted in a satisfactory lamp for resonance meter operation. A further improvement is presented by the use of a miniature bayonet base which assures positive contact of the lamp in its socket.

Lamp characteristics in general are discussed and the various points illustrated by means of curves. The various types of lamps available for home receivers and automotive receivers are described together with the applications for the various types. A typical mortality curve, showing the rate of failure throughout life for a group of lamps, is presented and the operation of the mortality curve in connection with the Underwriters' requirement of a 5000-hour life lamp for certain types of receivers is discussed.

Design considerations with respect to lamps being subjected to vibration or shock are covered and precautions in manufacturing to guard against open circuits within the lamp, are described.

The paper concludes with some simple precautions to be observed to guard against lamp failure in various types of receivers.

RATINGS AND OPERATING INFORMATION ON LARGE HIGH VACUUM TUBES

R. W. LARSON
(General Electric Company, Schenectady, N.Y.)
AND
E. E. SPITZER
(RCA Radiotron Division, RCA Manufacturing Company, Harrison, N.J.)

The Subcommittee on "Large High Vacuum Tubes" of the Technical Committee on Electronics, operating under the IRE Standards Committee, has as one of its objectives the study of ratings and operating information. The

study was allocated to the authors and the presentation of this material in th form of a paper may serve to bring out comments and suggestions which will l valuable to the Subcommittee.

The subject has been divided into three parts:

I. General Design Information
II. Maximum Ratings
III. Typical Operating Information

In publication by the manufacturer the above data usually appear in tabu lated form on a sheet which may be called a Technical Information Sheet. Th sheet together with a text on installation and operation and the characteristi curves forms an instruction booklet which is packed with each tube for th guidance of the purchaser. The instruction booklet plus a specification provide the information for the design of transmitting equipment in which the tube is t be used.

The purpose, method of preparation, and use of these data are discusse Each item of the Technical Information Sheet is considered in relation to th other parts and examples are shown to illustrate relationships.

A NEW TYPE OF GAS-FILLED AMPLIFIER TUBE

J. D. LeVan and P. T. Weeks
(Raytheon Production Corporation, Newton, Mass.)

The Raytheon Laboratories have had under development for several yea a gas- or vapor-filled amplifier tube. This paper describes the general feature of this type of tube and gives the detailed characteristics of some typical design

A distinctive feature of these gas-filled tubes is the introduction of a auxiliary grid-form electrode which serves as the anode for an ionizing discharg and at the same time as a cathode for the main electrode stream which is co trolled in the same manner as in an ordinary high vacuum tube. Due to the clos spacing of the main electrodes and the relatively low gas- or vapor-pressu employed, the main electron stream or plate current can be continuously co trolled by the voltage applied to the control grid, increasing as the negativ bias on the control grid is decreased and decreasing to cut-off as the grid bias made more negative. Within the voltage limits of each particular design of tub the presence of gas ions between the main electrodes only serves to neutraliz partially the space charge, the general form of the characteristics being the sam as for high vacuum tubes. The plate resistance however is characteristically lo and the mutual conductance much higher than in high vacuum tubes of co parable size. Because of the low space-charge characteristic it also follows tha high values of plate current and mutual conductance may be obtained at rel tively low values of plate voltage, although normal characteristics are also ob tained with plate voltages of several hundred volts.

This type of tube may be designed for use as a low-frequency or high-fr quency amplifier or oscillator and as a triode or screen-grid tetrode. It has bee made in sizes from a few watts to 50 watts rating, and has been used as an ultr high-frequency oscillator delivering 20 watts at 100 megacycles.

ANALYSIS OF THE OPERATION OF VACUUM TUBES AS CLASS C AMPLIFIERS

I. E. Mouromtseff and H. N. Kozanowski
(Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.)

The operation of class C amplifiers under carrier and modulated conditio is analyzed with the aid of constant-current charts. With these charts one ca

precalculate all operating factors such as output, efficiency, and grid driving power. The analysis discloses certain fundamental differences in the behavior of modulated amplifiers, connected with self-bias and fixed, or generator-bias, operation. Audio harmonic distortion traceable directly to the amplifier is discussed in detail, together with methods for "compensating" the grid excitation to eliminate this distortion and to increase the operating efficiency. Oscillograms of the audio relations in modulated class C amplifiers experimentally verify the theoretical conclusions. The problems of grid excitation power, "true" grid dissipation, and "effective" plate dissipation for modulated amplifiers are treated for three tubes differing only in their amplification factors.

A NEW TUBE FOR USE IN SUPERHETERODYNE FREQUENCY CONVERSION SYSTEMS

C. F. Nesslage, E. W. Herold, and W. A. Harris
(RCA Radiotron Division, RCA Manufacturing Company, Harrison, N.J.)

The disadvantages of existing methods of frequency mixing in superheterodyne sets are briefly summarized. The major disadvantage is found in high-frequency operation with comparatively low intermediate frequencies, where serious coupling exists between oscillator and signal circuits in spite of electrostatic screening. Suppressor grid modulation of a radio-frequency pentode largely overcomes many of the defects but the oscillator voltage required is large and the low plate resistance limits the gain. For these reasons a new tube has been developed wherein the disadvantages are largely overcome. The new tube contains five grids: the first grid is a remote cut-off signal grid, the second and fourth are screen grids, the third is used as the modulator grid controlled by a separate oscillator tube, and the fifth grid is a suppressor grid. The ideal characteristics of such a tube are derived. The actual characteristics of the tube developed are shown and a brief discussion of the results obtained is given. A discussion of electron current to a negative grid due to a peculiar transit time effect at high frequencies is given and it is shown that operation with sufficient grid bias reduces the phenomenon.

The characteristics of this tube also make it particularly suitable for use as a radio-frequency amplifier in receivers where the available automatic volume control or detector voltage is low; in this case the automatic volume control voltage is applied to both number 1 and number 3 grids.

Although not primarily intended for the purpose, the tube is also suitable for use in the volume expansion of recorded music. Such application provides an effective means of emphasizing the crescendos and diminuendos of the music. A demonstration of this application is given.

SOME THEORETICAL CONSIDERATIONS RELATING TO VACUUM TUBE DESIGN

G. D. O'Neill
(Hygrade Sylvania Corporation, Salem, Mass.)

In designing vacuum tubes it is usual to plan on using parts, where possible, that are standard in existing tubes. Data are obtained from the latter which are fitted into equations shown and which are based either on previously published equations or formulas introduced in the text. The design data obtained are used for making a sample lot of tubes which in turn furnish sufficient information for a closer approximation to the desired characteristics or, in comparatively simple cases (e.g., triodes) for final data.

An example of the use of this method is given, wherein the plate of an ex isting triode and the cathode of an existing pentode are to be used in a ne triode.

DESIGN AND EQUIPMENT OF A 50-KILOWATT BROADCAST STATIO FOR WOR

J. R. Poppele
(Station WOR, Newark, N.J.)
AND
F. W. Cunningham and A. W. Kishpaugh
(Bell Telephone Laboratories, Inc., New York City)

The design, construction, and operation of the modern high power broadca station presents problems of magnitude and complexity to the engineers respon sible for its success. It is the purpose of the authors to suggest, as an aid t engineers, methods of analysis of the many factors involved in the locatio the antenna design, the housing, and specification of equipment for a larg transmitter, offering the new WOR 50-kilowatt station as illustration.

The station location, together with the novel directional antenna, produce a maximum field strength toward both New York and Philadelphia, while limi ing radiation in the direction of the ocean and sparsely populated areas.

The layout of the transmitter building provides maximum convenience operation. The lighting, heating, and ventilation arrangements of the windowle building are unusual in design.

A serious attempt has been made to design and operate the equipment fo a performance consistent with advanced ideas of high fidelity. Curves showing th performance of the transmitter in regard to frequency characteristic and audi distortion are given, as well as the distribution of radiation.

NOTES ON INTERMEDIATE-FREQUENCY TRANSFORMER DESIG

F. W. Scheer
(S. W. Sickles Coil Company, Springfield, Mass.)

The effect of the intermediate frequency chosen on the gain and selectivit of amplifiers is pointed out. The computation and measurement of the sharpne of resonance of tuned transformers is outlined. Coils are studied in relation t the wire employed and form factor of the windings. The effects of tuning co densers, shields, and coupling of coils on the gain and selectivity are covered. Th calculation of stage gain and selectivity is treated. High fidelity receiver circui are considered and the use of two-winding and three-winding transformers com pared. Band-pass filters are discussed.

AN UNATTENDED ULTRA-SHORT-WAVE RADIOTELEPHONE SYSTE

N. F. Schlaack and F. A. Polkinghorn
(Bell Telephone Laboratories, Inc., New York City)

Some of the factors involved in the application of an ultra-high-frequen radio link to wire telephone plant are discussed. A description is given of a ultra-high-frequency radio circuit which has been set up and operated betwe Green Harbor and Provincetown, Mass. This circuit is used as a part of a reg lar toll telephone circuit between Boston and Provincetown. It has been fou that the equipment can remain in operation over considerable periods witho attention or adjustment.

GENERAL THEORY AND APPLICATION OF DYNAMIC COUPLING IN POWER TUBE DESIGN

Charles F. Stromeyer
(Revelation Patents Holding Company, New York City)

This paper presents a simplified method of driving a power tube without the need of coupling devices and grid-biasing means. The power section is one whose useful plate current versus grid voltage characteristic is realized only with positive values of grid voltage. Its low input impedance is in series with the cathode-ground circuit of the driver tube, and hence, the term "dynamic coupled." The impedance, also, automatically provides a negative bias for the grid of the driver, thereby eliminating external biasing.

Practical design consideration of the driver involves the working into a step-down load. It is shown that the distortion which is produced when working with such ratios, is minimized by degeneration. This is first treated with a pure resistive load. When the grid impedance is the load, a further reduction in distortion is shown for then the ratio of plate-to-load impedance more nearly remains constant throughout a signal excursion. Graphical projection of the reflected grid impedance of the power section on the driver's plate characteristic is treated in detail.

The remaining part of the paper deals with a commercial application of these principles. Certain design considerations for a tube embodying both driver and power sections are discussed. A current surge phenomenon caused by secondary emission and a practical means for its elimination is expounded. The delayed point at which the driver's grid begins drawing current is shown to be particularly advantageous in push-pull circuits. The tube's electrical and economical advantages are compared to contemporary audio systems.

ELECTRON BEAMS AND THEIR APPLICATION IN LOW VOLTAGE DEVICES

Harry C. Thompson
(RCA Radiotron Division, RCA Manufacturing Company, Harrison, N.J.)

A study has been made of the segregation into beams of the space current in devices of the over-all size of commercial receiver tubes and at potentials less than 300 volts. Electrode coatings of luminescent material were used to make beam traces apparent on any or all electrodes.

Qualitative relationships between beam formations and relative electrode potentials are stated.

Space currents of a few milliamperes have been concentrated into beams less than 0.010 inch wide in simple structures.

Special control grids associated with ordinary cathodes have been found to combine good space-current control with effective beam formation so that the properties of beam formation, control of beam width, direction, and current can be combined in a single device.

It has been found that the segregation into beams by simple beam-forming structures is sufficiently effective to make possible a radical reduction in the ratio of percentage of space current to a positive electrode to percentage of projected area of that electrode when the latter is situated between cathode and ultimate anode.

The relationships between beam widths and electrode potentials have bee found to be such that the mutual volt-ampere relations can be radically altere from those hitherto utilized. Linear, saturation, and special volt-ampere relation can be obtained. Individual electrode volt-ampere relations can be altered b utilizing the action of the field of such an electrode upon the width and directio of the beam impinging upon that electrode independently of interelectrode cou pling. A variety of negative conductance devices have been made on this principl

AUTOMATIC FREQUENCY CONTROL

CHARLES TRAVIS
(RCA License Laboratory, New York City)

The title refers to the control of the local oscillator frequency in a supe heterodyne receiver for the purpose of centering the signal carrier in the inte mediate-frequency band in spite of inaccuracies of manual tuning and potenti "oscillator drift."

A system is described to accomplish this by electronic means. It consists o two units, one a detector preceded by frequency discriminating circuits and control unit acted upon by the bias output of the above detector, to var the oscillator frequency properly. Circuits for the control unit are shown an the manner of operation of the system is discussed.

Meeting of the Board of Directors

The regular May meeting of the Board of Directors was held o the first of the month at the Institute office and those present wer Stuart Ballantine, president; Melville Eastham, treasurer; O. H. Cald well, Alfred N. Goldsmith, Virgil M. Graham, R. A. Heising, J. V. L Hogan, L. M. Hull, F. A. Kolster, George Lewis, E. L. Nelson, Harade Pratt, H. M. Turner, A. F. Van Dyck, L. E. Whittemore, Willia Wilson, and H. P. Westman, secretary.

Fifty-one Associates and thirteen Students were admitted t membership.

Instructions were issued for preparing an accumulative index fo the PROCEEDINGS covering all issues up to December, 1935, to be pub lished early in 1936.

The Emergency Employment Service registration now totals 74 and of the eight jobs which came to our attention during the month one was filled.

The Institute Medal of Honor was voted to Balth. van der Po Jr. for his fundamental studies and contributions in the fields of circu theory and electromagnetic wave propagation phenomena.

The Morris Liebmann Memorial Prize will be bestowed upon F B. Llewellyn for his analysis and disclosures of the effects and reaction within vacuum tubes at ultra-high frequencies.

Nominations for candidates for officers to be elected during the ter part of this year were prepared and are given in an announce- nt following these minutes.

The committee which is studying the problems of licensing of gineers submitted a progress report which was discussed. Insufficient ta are available at this time to permit the preparation of material publication but it is anticipated that a statement can be presented the PROCEEDINGS in the early fall.

Nominations and election of Officers

In accordance with the requirements of the Institute Constitution, ticle VII of that document is reprinted herewith and is followed by list of nominations submitted to the membership by the Board of rectors.

ARTICLE VII

NOMINATION AND ELECTION OF PRESIDENT, VICE PRESIDENT, AND THREE DIRECTORS AND APPOINTMENT OF SECRETARY, TREASURER, AND FIVE DIRECTORS

SEC. 1—On or before July 1st of each year the Board of Directors shall l for nominations by petition and shall at the same time submit to qualified ters a list of the Board's nominations containing at least two names for each ctive office, together with a copy of this article.

Nomination by petition shall be made by letter to the Board of Directors ting forth the name of the proposed candidate and the office for which it is de- ed he be nominated. For acceptance a letter of petition must reach the execu- e office before August 15th of any year, and shall be signed by at least thirty- e Fellows, Members, or Associates.

Each proposed nominee shall be consulted and if he so requests his name ll be withdrawn. The names of proposed nominees who are not eligible under e Constitution, as to grade of membership or otherwise, shall be withdrawn by e Board.

On or before September 15th, the Board of Directors shall submit to the Fel- s, Members, and Associates in good standing as of September 1st, a list, of minees for the offices of President, Vice President, and three Directors. This shall comprise at least two names for each office, the names being arranged in habetical order and shall be without indication as to whether the nominees re proposed by the Board or by petition. The ballot shall carry a statement to effect that the order of the names is alphabetical for convenience only and icates no preference.

Fellows, Members, and Associates shall vote for the officers whose names pear on the list of nominees, by written ballots in plain sealed envelopes, en- sed within mailing envelopes marked "Ballot" and bearing the member's tten signature. No ballots within unsigned outer envelopes shall be counted. votes by proxy shall be counted. Only ballots arriving at the executive office or to October 25th shall be counted. Ballots shall be checked, opened, and nted under the supervision of a Committee of Tellers, between October 25th

and the first Wednesday of November. The result of the count shall be repo to the Board of Directors at its first meeting in November and the nominee President and Vice President and the three nominees for Directors receiving greatest number of votes shall be declared elected. In the event of a tie vote Board shall choose by lot between the nominees involved.

Sec. 2—The Treasurer, Secretary, and five appointive Directors sha appointed by the Board of Directors at its annual meeting for a term of one or until their successors be appointed.

For President

L. A. Hazeltine — F. A. Kolster

For Vice President

Valdemar Poulsen — K. W. Wagner

For Directors

E. H. Armstrong — Virgil M. Graham
W. R. G. Baker — George Lewis
H. H. Beverage — A. F. Van Dyck

Proceedings of the Institute of Radio Engineers
olume 23, Number 6 *June, 1935*

TECHNICAL PAPERS

MAGE SUPPRESSION IN SUPERHETERODYNE RECEIVERS*

By

HAROLD A. WHEELER

(Hazeltine Corporation, Jersey City, New Jersey)

Summary—*Superheterodyne receivers are particularly sensitive to interference the intermediate frequency and at the image frequency. Several types of selective rcuits are described for coupling the antenna to the grid of the first tube which ave especially great selectivity against such interference. The number of selective rcuits which must be tuned to the signal is thereby minimized. Performance curves re given for receivers having intermediate frequencies of 175 or 450 kilocycles.*

IT IS well known that a superheterodyne receiver, when tuned to a desired signal, is particularly sensitive to interference at certain other frequencies, which are called spurious response frequencies. he principal spurious response frequencies are the intermediate fre- uency and the image frequency. The latter is usually higher than he signal frequency, and differs therefrom by twice the intermediate requency. The most interference is likely to occur at the intermediate requency or the image frequency, whichever is closer to the signal requency. In a broadcast receiver having an intermediate frequency f 175 kilocycles, the image frequency is more likely to be closer to the gnal frequency, while in a broadcast receiving having an intermediate requency of 450 kilocycles, the latter is more likely to be closer to the gnal frequency.

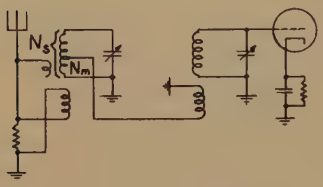
One or more selective circuits, tuned to the signal, are used to re- uce interference at spurious response frequencies. In addition, special rcuits have been devised for further reducing interference without creasing the number of tuned circuits. Some of these circuits, together ith performance curves, are the subject of this paper. The most ttention has been paid to the reduction of image interference, which termed image suppression. The image suppression circuits will be escribed with reference to image frequencies higher than the signal equencies.

Fig. 1 shows a simple double tuned selector for coupling the an- nna to the grid of the first vacuum tube in a superheterodyne receiver.

* Decimal classification: R361.2. Original manuscript received by the stitute, February 18, 1935. Presented before New York Meeting, April 5, 33, as part of paper "Image Suppression and Oscillator-Modulators in Super- terodyne Receivers."

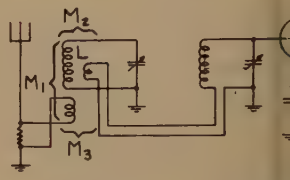
The antenna is coupled to the lower part of the first tuned coil, cap
tively by means of an open-end primary coil, and inductively by me
of a high inductance primary coil which broadly resonates the ante
circuit just below the broadcast band. A tap on the first tuned co
connected to another high inductance primary coil which is inductiv
coupled to the second tuned coil.

The advantage of this circuit resides in the tap connection. Hav
tuned the circuits to the signal, it is found that image frequency
rents in the first tuned circuit determine a point on the first tuned
which has zero image voltage relative to ground. The equation of



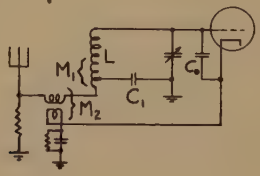
$$\frac{N_m}{N_s} = 1 - \frac{f_s^2}{f_m^2}$$

Fig. 1



$$\frac{M_1 M_2}{M_3 L} = 1 - \frac{f_s^2}{f_m^2}$$

Fig. 2



$$\frac{f_{12}^2}{f_m^2} + \frac{M_1}{M_2} = \frac{f_m^2}{f_s^2} - 1 - \frac{f_m^2}{f_0^2}, \quad f_{12} = \frac{1}{2\pi\sqrt{C_1 M_2}}, \quad f_0 = \frac{1}{2\pi\sqrt{LC_0}}$$

Fig. 3

1 indicates approximately the location of this image suppression po
N denotes number of turns on the coil, f denotes frequency, and
subscripts s and m refer to signal and image, respectively.

The ratio of signal-to-image frequency varies over the broad
band, so that the optimum position of the tap depends on the tu
frequency. However, the tap can be located at a compromise po
such that a considerable advantage is obtained over the entire ba
the advantage being greatest near the middle of the band.

This circuit was very widely used in the first commercial five-t
superheterodyne receivers, with an intermediate frequency of
kilocycles. In these receivers, the double tuned selector was conne
directly to the modulator (or first detector).

Fig. 2 shows a simplified double tuned selector capable of nearly the same performance as that of Fig. 1. The equation of Fig. 2 gives approximately the condition for optimum image suppression. This equation is satisfied structurally by sliding the coupling coil along the first tuned coil, varying M_2 and M_3 in opposite directions until the best compromise design is found. The best position of the coupling coil is usually a little above the lower end of the tuned coil, as indicated in the diagram.

Fig. 3 shows an improved type of single tuned selector which is widely used in recent and contemporary receivers, connected in some cases to a tuned radio-frequency amplifier and in other cases directly to the modulator. The antenna is coupled to the tuned circuit by a large condenser C_1, having about ten times the maximum capacitance of the tuning condenser, and in addition by a very small mutual inductance M_1, which may be omitted in some cases. A series coil and shunt resistance serve to resonate broadly the antenna circuit near the middle of the operating frequency band, thereby increasing the antenna signal current and also improving the selectivity against interference outside of the operating band.

The image suppression is obtained by the cathode coil, which is coupled to the antenna circuit by mutual inductance M_2. Having tuned the circuit to the signal by the tuning condenser, it is found that image frequency currents in the antenna circuit produce a small image voltage on the grid of the first tube. The cathode coil applies a similar image voltage on the cathode of the tube, which counterbalances in the tube any effect of the small image voltage on the grid. The equation of Fig. 3 gives approximately the condition for optimum image suppression. The inherent direct capacitance between grid and cathode, denoted C_0, has an appreciable effect and should be kept small.

For this circuit there are two terms on the left side of the equation, both under control of the designer. The first term has the major effect, and the second term has a minor effect which is more important at higher frequencies. As a result, this circuit is capable of optimum suppression at two points in the operating band, and very nearly optimum throughout the entire band.

The image suppression is independent of the self-impedance of the antenna circuit, which allows considerable freedom of design. Best results have been obtained by making the antenna circuit resonant in the operating band, and damping the resonance by resistance to prevent the reflection of excessive resistance into the tuned circuit. Under these conditions, the tuning is practically independent of antenna characteristics, and the antenna-to-grid gain is good.

Fig. 4 shows performance curves on the circuit of Fig. 3, design for 175 kilocycles intermediate frequency, the image frequency th being 350 kilocycles above the signal frequency. The curve across t top is the voltage gain curve from the antenna to the grid of the fi tube. The broad peak in the gain curve results from the broad resonan of the antenna circuit, which has already been mentioned. The respon curves show the selectivity of the circuit when tuned to 600, 1000, a 1400 kilocycles, respectively. On each curve, the frequency of greate suppression is just 350 kilocycles above the frequency of resonan

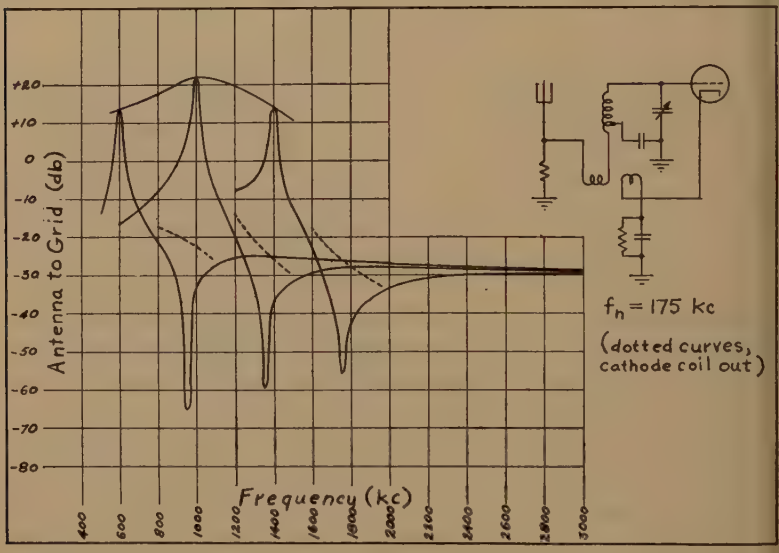


Fig. 4

which results in great attenuation of image interference. The ima ratio for this single tuned selector is from 66 to 80 decibels, or 20 to 10,000 times, over the entire operating range. The greater values a effective where the image frequencies are also in the broadcast ba and are therefore more likely to cause interference. In this circuit, t improvement due to the image suppression is equivalent to anoth tuned selective circuit, as far as image interference is concerned. T advantage is seen by comparison with the dotted curves which w observed with the image suppression disconnected. It is importa that the auxiliary circuits used to attenuate the image do not introdu any spurious resonance peaks in the response curves, especially at t higher frequencies. This was one of the problems encountered, wh was solved by this circuit, as shown by the curves.

The circuit of Fig. 4 is used in some commerical receivers which also include a tuned radio-frequency amplifier stage. In these cases, the resulting image ratio for the two tuned selective circuits ranges from 100 to 120 decibels, or 100,000 to 1,000,000 times, which is found to be sufficient for very nearly all conditions. This image ratio is largely limited by refinements in shielding and grounding, rather than by the capabilities of the image suppression circuit.

In receivers having image suppression, it is found that the image frequency may become less important than other spurious response

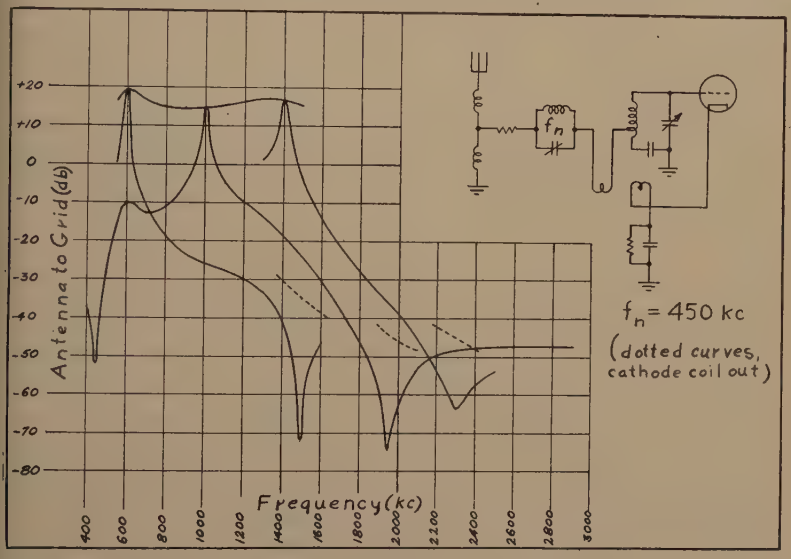


Fig. 5

frequencies, most of which are higher than the signal frequency. In receivers having an intermediate frequency near the lower limit of the operating band, this also becomes a source of interference, which is amplified directly by the intermediate-frequency amplifier.

Fig. 5 shows a modification of the circuit of Fig. 4, together with similar performance curves. This improved circuit is intended to feed the modulator tube in receivers having only a single tuned selector, and using an intermediate frequency of 450 kilocycles. The image frequency is therefore 900 kilocycles above the signal frequency. The curves show that the maximum suppression occurs at the image frequency, exactly when the receiver is tuned to 600 or 1400 kilocycles, and approximately when tuned to 1000 kilocycles. As far as broadcast interference on the image frequency is concerned, it is possible only

when the receiver is tuned between 550 and 600 kilocycles, in whic case the image ratio is 90 decibels or 30,000 times.

Three other improvements are shown in Fig. 5. The gain curve a the top is held more nearly uniform by making the antenna circu doubly resonant in the broadcast band. A trap is included whic greatly attenuates interference at the 450-kilocycle intermediate fr quency, as shown by the curves. The action of the trap is about th same, regardless of the tuning. This trap also coöperates in improvin the gain curve. The attenuation at frequencies higher than the imag frequency is considerably improved as compared with Fig. 4.

In any of these circuits, additional filtering ahead of the first tune circuit would result in further reduction of interference outside th broadcast band. In Fig. 4, the antenna circuit is roughly equivalent t a half-section band-pass filter. In Fig. 5, the antenna circuit has i addition a half-section high-pass filter, containing the intermediat frequency trap. A remarkable degree of selection is obtained with on variable tuned circuit, by the combination of means for suppressin the image and means for filtering out all interference outside the ope ating band. Better selection is needed only in very sensitive receive operating in the neighborhood of powerful transmitters.

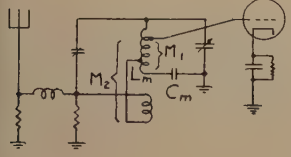
The circuit of Fig. 6 represents a different arrangement whose pe formance is nearly as good as Fig. 5, and whose cost is considerabl less, due to some simplification of the circuit. This circuit is intende for use in low price receivers having an intermediate frequency of 45 kilocycles.

The main coupling between antenna and tuned circuits is provide by L_m, M_1, M_2, and C_m, indicated in the diagram. The inductance an condenser components have opposing coupling effects, and the r sultant coupling is a minimum at the intermediate frequency f_n whe the coupling components are proportioned according to (6). The tot inductance and resistance in the antenna circuit is chosen to make broadly resonant within the broadcast band, just above 550 kilocycl where the resultant coupling is less because of the proximity to 45 kilocycles. In this way, the gain is maintained nearly uniform, an the tuning is made nearly independent of antenna characteristics.

The image suppression is mainly accomplished by the grid tap o the tuned coil, in the manner described in connection with Fig. 1. Th image suppression is modified by the small condenser of a few micr microfarads connected between the top of the tuned circuit and point in the antenna circuit. These two factors permit of maximu image suppression when the receiver is tuned to 600 or 1400 kilocycle and nearly maximum when tuned to any frequency in the broadca

ange. The second resistance in the antenna circuit is to prevent a peak vhich would otherwise occur in the response curve at about four negacycles.

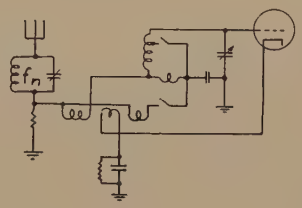
The circuit of Fig. 7 is a single tuned selector designed for operation ver two different frequency bands. It is found especially useful in eceivers covering the broadcast band and the next higher band, and aving an intermediate frequency of 450 kilocycles. The selector is onnected directly to the modulator. In fundamental operation, this ircuit is like the other cathode coil circuits, shown in Figs. 3 to 5. An ntermediate-frequency trap is included in the antenna lead. Two



$$(L_m + M_1 + M_2)C_m = \frac{1}{4\pi^2 f_n^2}$$

$f_n = 450$ kc

Fig. 6



$$f_s = \begin{cases} 550 - 1400 \text{ kc} \\ 1400 - 3500 \text{ kc} \end{cases}$$

$f_n = 450$ kc

Fig. 7.

witches are connected so as to change four properties of the circuit s follows: (1) the tuned circuit inductance; (2) the coupling reactance ommon to the antenna and tuned circuits; (3) the mutual inductance o the cathode coil; (4) the antenna circuit inductance.

In the course of the work on image suppression, many other circuits ave been devised and tested. Some of these other circuits are also in ommercial use at the present time. For example, special circuits have een designed to met the requirements for European receivers, which ust cover the broadcast band and also a lower frequency band. It found that image suppression circuits lend themselves also to other ses, which fall outside the scope of this discussion.

The writer gratefully acknowledges the contributions and assistnce, in the work on the subject of this paper, of Messrs. J. K. Johnson, . P. Case, V. E. Whitman and other engineers of the Hazeltine Corporation.

Discussion

J. C. Smith:[1] The paper by Mr. H. A. Wheeler is part of a paper titl "Image Suppression and Oscillator-Modulators in Superheterodyne Receiver which was presented at the April, 1933, New York meeting of the Institu Much of the material presented on the oscillator-modulator on that occasion h been published elsewhere and readers are referred to the following articles:

"The Emission Valve Modulator for Superheterodynes," *Electronics*, Marc 1933, page 76.

"The Emission Valve Modulator for Superheterodyne Receivers," *Pr ceedings of the Radio Club of America*, April, 1933, page 23.

"The Hexode Vacuum Tube," *Radio Engineering*, April, 1933, page 12.

The following discussion was presented at the New York meeting at whi Mr. Wheeler's paper was originally given. While it is confined entirely to th portion of the paper concerning the oscillator-modulator, it is presented here a matter of record.

I have particularly enjoyed Mr. Wheeler's paper this evening because my part in unitube detector-oscillator developments which originated at Ca den and were carried through by engineers of the RCA Victor and the RC Radiotron Companies. These developments culminated commercially in t 2A7 and 6A7 pentagrid converters and a short résumé of them at this time m be of interest to the members. I hope you will pardon me if for the sake of co tinuity in presentation of the ideas involved I repeat points which Mr. Whee has just discussed.

For some years a number of circuits have been known which were availa for use as a unitube detector-oscillator, but they were in general possessed very serious defects. An analysis of the problems involved indicated that i device were developed with signal voltage and local oscillator voltage effectiv in parallel, i.e., in an additive relationship, curvature of a tube characteristic a probably an external coupling of the circuits would be necessary. Mathema cally, this simply involves the summation of the signal and oscillator volta and the expansion of this sum in a power series which represents the tube ch acteristic. Sum and difference terms and harmonics result and the desired sig is then selected and amplified. An alternative view considers that the oscilla voltage periodically varies the transconductance of the tube. This produce cross product of the signal and oscillator voltages with resulting sum and diff ence terms.

A method of accomplishing this end without curvature of the tube charact istic or intercoupling of the circuits was seen to lie in the use of grids act successively upon the electron stream, in series as it were. A tube was theref devised with two negatively polarized control grids separated by an interpo positive grid. A plate was external to the whole, with appropriate screening. the simplest form with successively a cathode, a negative grid, a positive gr a second negative grid and a plate, there are transconductances between ea of the negative grids and the positive elements. Any one of these transc ductances may be chosen to feed energy back to the appropriate negative g to produce self-oscillation, while a signal may be placed upon the other negat grid. Thus one could build up around this tube numerous circuit combinati which would give the desired cross product of signal and local oscillator voltag

Certain other factors, however, served to restrict the choice of circuit co

[1] Radio Manufacturing Company, RCA Victor Division, Camden, New Jersey.

binations. The most important of these was the desirability of controlling the gain of the tube through the gain control system of the receiver. It was determined that this control could best be placed upon the outer negative grid. The control grid was provided with a positively polarized screen which, in addition to performing the usual functions of a screen grid, aided in raising the output impedance of the tube. The use of complete shielding increased the total cathode current by about two milliamperes, but it was considered that this was of much less relative importance than the advantages obtained by complete shielding. We then have the A-7 pentagrid converter tube in its present form with cathode, oscillator grid, oscillator anode, screen, control grid of the exponential type, second screen, and output plate, the positive screen elements being connected together and brought out on a common lead. Since the oscillator anode has the function of furnishing a transconductance with the oscillator grid, it is unnecessary that it be in the form of a grid; it may consist simply of two side rods parallel to the cathode. There are no particularly novel or unusual features to be taken into consideration in designing a superheterodyne receiver to use the A-7. The design of the radio-frequency input coil, the intermediate-frequency transformers, and the gang tuning condensers is conventional.

It is physically very illuminating to think of the tube as being an emission valve, as Mr. Wheeler points out, having a virtual cathode for which the supply of electrons is controlled by variation of the oscillator grid potential. Mathematically, as Mr. Wheeler has indicated this evening, the operation of the tube can be expressed in terms of developments of the usual tube characteristics, particularly of transconductance. If we assume a fixed bias on the signal grid, we can determine the transconductance $(\partial I_p/\partial E_{g4})$ for a range of values of E_{g1}, the oscillator grid voltage, and plot the resulting curve, which will in general approximate a straight line. Knowing the oscillator grid voltage and operating point, it is possible to calculate or measure the various components of plate current at the various frequencies. If we then define the conversion transconductance as the ratio of the desired intermediate-frequency component of plate current to the control-grid signal voltage as that signal approaches zero as a limiting value, we have a characteristic which is a figure of merit of the tube, corresponding in a measure to the transconductance of a screen-grid tube. I say it corresponds in a measure, because it is not, strictly speaking, a function of the tube alone, but also of the associated oscillator circuit, its operating point, and wave form. Practically speaking, however, the value can be used as a means of calculating the gain of the tube for a given value of plate impedance, just as S_m is used in the ordinary tube.

It is interesting to note that while this development was undertaken primarily for economic reasons, as a means of simplifying the design of the receiver, eliminating a tube and certain associated parts, and saving space, it was realized that there would result the attainment of certain technical advantages as compared with the usual two-tube system. Among those which have resulted there might be listed the following: a high translation gain; a greater volume control effectiveness; the elimination of the necessity for intercoupling between radio-frequency and oscillator and resultant freedom of mechanical design, and the removal of troubles associated with that intercoupling. Thus we are doubly fortunate in obtaining both economic and technical improvements in the developments we have heard discussed this evening.

Proceedings of the Institute of Radio Engineers
Volume 23, Number 6 *June, 19*

THE DESIGN AND TESTING OF MULTIRANGE RECEIVER

By

Daniel E. Harnett and Nelson P. Case
(Hazeltine Corporation, Jersey City, New Jersey)

Summary—*The principal difficulties in the design of high-frequency receiv reside in the complexity of the multirange circuits. Several circuits and a unit sembly arrangement are described which improve the frequency calibration a simplify the design. Testing is facilitated by the use of simplified signal generat having "piston" attenuators. The attenuator comprises a pair of coplanar coils, axial coils, or condenser plates, one fixed and one movable axially in a moderat long cylindrical copper shield. The attenuation in decibels is directly proportio to the displacement of the movable element, and the calibration can be comput*

THE problem of properly designing multirange receivers h existed for many years, but until about three years ago the on fields for such receivers were commercial communication servic and amateur work. Receivers for these services could be of the labor tory type, with each receiver more or less of an individual proble production difficulties and expense were not important factors, a the completed receivers were normally used by skilled technicia

Presently, however, a faint but insistent demand commenced be heard from the large body of broadcast listeners that they be su plied with means whereby they could listen to programs, perhaps little interest in themselves, but of great popular appeal because th originated at great distances. The first answer to this demand took t form of a "converter," to be installed as an accessory to the broadca receiver already in the listener's home. The converter was mere an extra oscillator and modulator, arranged to give a modulated outp at a frequency within the normal tuning range of the broadcast ceiver. Like most such afterthoughts, the converter had serious defe in performance, but at least high-frequency signals could be receiv and thereby public interest was further aroused.

The next step in the progress of the all-wave receiver was the logi one of making the modulator and oscillator circuits of the receiver self capable of tuning over the high-frequency ranges, thus eliminati an unnecessary duplication of functions. Various schemes were tri to maintain the broadcast reception at or near the standard to wh the public was accustomed, such as preselectors and radio-frequen amplifiers for the broadcast band only. Fundamentally, of course, t

* Decimal classification: R261. Original manuscript received by the stitute, February 18, 1935. Presented before Ninth Annual Convention, Ph delphia, Pa., May 30, 1934.

igher frequency ranges really needed the improvements more than id the broadcast range, because of weaker signals, less efficient cir- uits, and inherent selectivity considerations. However, multirange eceivers were still in the laboratory stage of design, and laboratory esigns attempted on the production line encountered such grave ifficulties that nothing but the simplest type of high-frequency cir- uits was at all practicable.

At this stage of development, the design work was largely a matter f cut and try; the necessary tools for accurate measurement of results ere not yet developed, and such matters as stage gains and alignment f high-frequency circuits received only cursory attention, just suffi- ient to produce a usable receiver.

To progress beyond this point, it was necessary that the tools of esign be improved to the point where the defects of existing receivers ould be accurately investigated, and the pathway to further improve- ent could be pointed out. The principal need was for an all-wave ignal generator with high output, open frequency scales, and accurate ttentuation, which could be handled with convenience and speed.

In view of the important rôle played by standard signal generators n the practical work of designing all-wave receivers, it is proposed to iscuss briefly in this paper several types of attenuators for such in- truments.

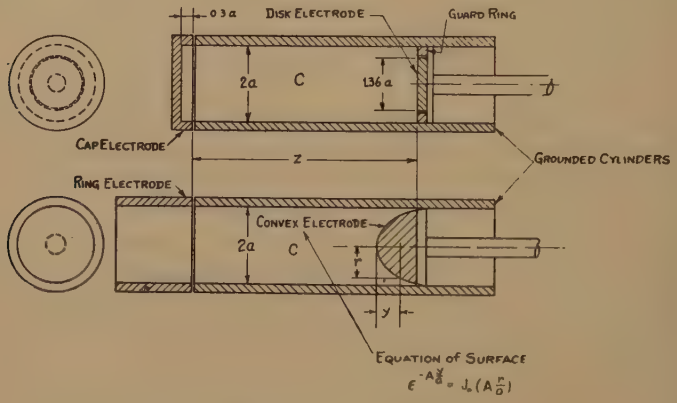
Important points of difference between the various types of gener- tors lie in the attenuators and in the methods of changing from one requency range to another. Regarding the latter point, most all-wave enerators produced thus far have used plug-in coils, but the tendency ill probably be toward switching of permanently mounted coils, ecause of the time lost in changing coils, especially where the range f one coil is insufficient to cover a single range of an all-wave receiver, s is usually the case.

Of the three types of attenuator (resistance, capacitance, and in- uctance), the first has been so thoroughly investigated that its ad- antages and limitations are generally known.

Regarding the variable capacitance and variable mutual inductance ypes of attenuators, there is so great a variety of possible arrangements hat it would be beyond the scope of this paper to attempt to treat all f them. Accordingly, this discussion will be limited to those arrange- ents wherein a magnetic or electrostatic field is generated at one end f a long conducting tube and is attenuated exponentially along the ube. The signal voltage delivered to the output terminals is propor- onal to the intensity of the field at a pick-up device which is movable long the axis of the tube. Because of the exponential change in field

strength, the attenuation in decibels varies linearly with the distan between the source and the pick-up. To take advantage of this line relation, the attenuator output is indicated in decibels below one vo rather than in microvolts. The rate of attenuation is accurately dete mined by calculation.

Fig. 1 shows two forms of the variable capacitance type of attenu tor. With any shape of electrodes, the rate of attenuation is 20 decibels per radius along the axis of a circular tube, for large separati of the electrodes. With electrodes of the two forms shown, the separ



$$\frac{C}{C_0} = \epsilon^{-A(z/a)}$$

$$A = \begin{cases} 2.405 \text{ napiers} \\ 20.9 \text{ decibels} \end{cases} \text{per radius.}$$

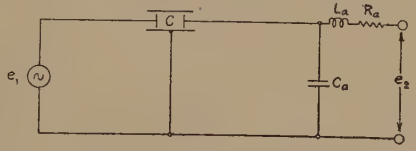
(19.3 decibels in square cylinder.)

Fig. 1—Piston attenuator, condenser in circular cylinder.

tion "z" can be reduced nearly to zero, without appreciable departu from this rate of attenuation. The capacitance between the ring a the convex electrode is greater at this point than that between the c and the disk electrode, resulting in about 10 decibels greater maximu output from the former arrangement, with reasonable tolerances.

A circuit arrangement for the capacitive attenuator is shown Fig. 2. The circuit elements C_a, R_a, and L_a comprise the dummy a tenna. The open-circuit output voltage of this circuit depends only the values of C and C_a. The principal advantages of the capaciti attenuator are that it has no coils to be changed for different rang and that the attenuation is independent of frequency for a given val of C_a.

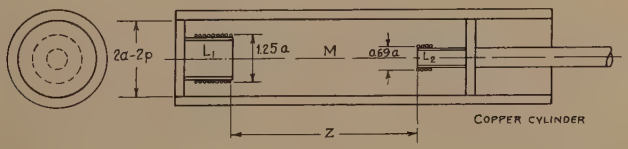
Fig. 3 shows a piston attenuator having mutual inductance between two coaxial coils. Using a circular cylinder for the tube and keeping the coils sufficiently separated, the rate of attenuation for this type is 33.3 decibels per radius, where the effective radius "a" is the measured inside radius of the cylinder plus the "depth of penetration". Since the depth of penetration varies inversely as the square root of the frequency, the rate of attenuation varies slightly with frequency. It



$$\frac{e_2}{e_1} = \frac{C}{C_a + C} = \text{approx.} \frac{C}{C_a} \text{ when } C << C_a.$$

Fig.12

is found in practice that a tube of sufficient diameter to give the desired length of attenuator scale is large enough so that the error caused by neglecting the variation of the depth of penetration is negligible over the useful range of attenuation. This error in a two-inch copper tube may be taken as an example. If the scale is marked correctly for 1000 kilocycles the actual attenuation at 25 megacycles will be about one-fourth decibel in 100 more than indicated, and at 150 kilocycles will be about one-half decibel in 100 less than indicated.



Depth of penetration: $p = \dfrac{1}{2\pi\sqrt{f\sigma}} = 2.6$ mils at 1 mc

$$\frac{M}{M_0} = \epsilon^{-A(z/a)}$$

A = { 3.832 napiers / 33.3 decibels } per radius

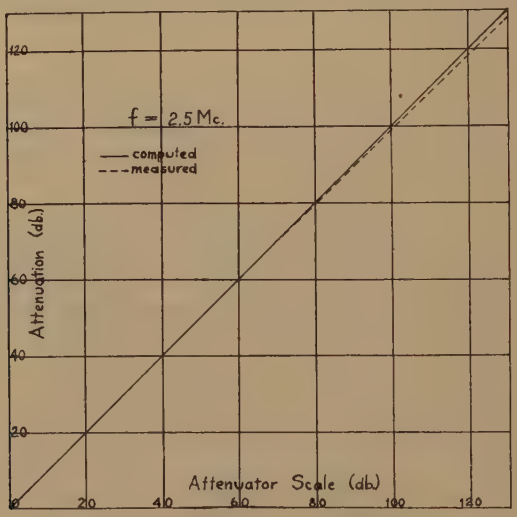
(27.3 decibels in square cylinder)

Fig. 3—Piston attenuator, coaxial coils in circular cylinder.

When the coils are close together, the diameters of the coils have a small effect on the rate of attenuation. Choosing the values shown on Fig. 3 for the coil diameters results in keeping the rate of attenuation substantially uniform up to the setting at which the load reaction of the output circuit on the input circuit becomes appreciable. The proper

coil diameter is that which makes the flux configuration close to t input coil nearly the same as that at a considerable distance from t coil. Otherwise the field pattern will be distorted by the coil and t normal rate of attenuation will not hold when the coils are close.

There are two sources of errors in attenuation which must be ca fully minimized in mutual inductance attenuators having coaxial coi One is incidental capacitive coupling and the other is departure fro axial symmetry. The latter causes a transverse magnetic field. T capacitive coupling and the "transverse" inductive coupling are su



Mc	Error ±2 db at
1	116 db
2.5	130
6	120
15	106

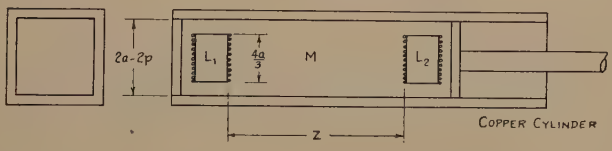
Fig. 4

ject to much less attenuation than the desired "axial" inductive c pling, and therefore become more detrimental with increasing atten tion. The incidental capacitive coupling is minimized by groundi the near ends of the two coils. When the coils have very few turns, connecting leads cause appreciable transverse field. This source error can be minimized by arranging the plane of the leads to one perpendicular to the plane of the leads to the other coil, both pla including the axis of the cylinder.

Fig. 4 shows the accuracy of calibration of an attenuator which been built with coaxial coils. The cylinder is a seamless copper t two inches in diameter. When all the known sources of error have b

carefully minimized, the calculated calibration agrees with the experimental to limits closer than can be measured with the usual laboratory equipment. The accuracy is shown to be good over 120 decibels variation. This may be the range from one volt to one microvolt or from one-third volt to one-third microvolt.

Fig. 5 shows another form of mutual inductance attenuator, having coplanar coils in a square cylinder. In this form, the desired inductive coupling is caused by the transverse field which was a possible source of error in the attenuator having coaxial coils. The inductive coupling between coplanar coils has the smallest rate of attenuation of all forms of inductive and capacitive coupling in a closed cylinder. Therefore the other forms of inductive coupling and capacitive coupling are attenuated more than the desired coupling, and become less detrimental with an increasing amount of attenuation. The coil length indicated is chosen to maintain a substantially uniform rate of attenuation when the separation of the coils is reduced nearly to zero.



Depth of penetration: $p = \dfrac{1}{2\pi\sqrt{f\sigma}} = 2.6$ mils at 1 mc

$$\frac{M}{M_0} = \epsilon^{-A(z/a)}$$

$$A = \left\{ \begin{matrix} \dfrac{\pi}{2} \text{ napiers} \\ 13.64 \text{ decibels} \end{matrix} \right\} \text{per radius}$$

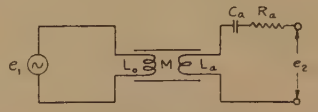
(16.0 decibels in circular cylinder)

Fig. 5—Piston attenuator, coplanar coils in square cylinder.

A preferred design of this attenuator has rectangular coils in a square cylinder. The near sides of the coils have greatest mutual inductance. The shielding surfaces close to the other sides of the coils contribute materially toward increasing the maximum coupling. Such an attenuator has been built, having 40 per cent as the maximum usable coefficient of coupling between the coplanar coils.

Fig. 6 shows two alternative circuits for connecting a mutual inductance attenuator in a signal generator. The upper circuit is a simple arrangement in which the input coil L_o may be the oscillator coil and the output coil L_a may be the inductance of a dummy antenna. This circuit is well adapted to the use of plug-in coils for different frequency

ranges. The coils may be proportioned to give the same maximu output in each range. Such an arrangement has been incorporated i several signal generators with piston attenuators having coaxial coi in a two-inch copper tube. The piston is removed from one end of th cylinder to permit changing the plug-in coils. The oscillator coil changed with the aid of a long rod or a bayonet attachment on th piston. The attenuation scale is engraved on the piston rod, which als carries the output terminals connected to the pick-up coil. The fr quency range from 100 kilocycles to 24 megacycles is covered with s pairs of coils.



$$\frac{e_2}{e_1} = \frac{M}{L_o} = k\sqrt{\frac{L_a}{L_o}}$$

$$k^2 = \frac{M}{L_o L_a}$$

$$\frac{e_2}{e_1} = \frac{kk_1k_2}{1-k_1^2-k^2}\sqrt{\frac{L_a}{L_0}} = \text{approx.}\frac{kk_1k_2}{1-k_1^2}\sqrt{\frac{L_a}{L_0}} \text{ when } k^2 << 1.$$

$$k^2 = \frac{M^2}{(L_1+L_1')\ (L_2+L_2')} \qquad k_1^2 = \frac{M_1^2}{L_0(L_1+L_1')} \qquad k_2^2 = \frac{M_2^2}{L_a(L_2+L_2'}$$

Fig. 6

The lower circuit of Fig. 6 is an arrangement for using the same tw attenuator coils over a wide range of frequency. The attenuator coi are made of sufficiently small inductance to be operable at the highe frequency. The input and output transformers shown in dotted circl are changed from range to range, preferably by switching. If plug-i coils are used, only the input coil L_o and the output coil L_a need b changed. In either case, the former may be the oscillator coil and th latter may be the inductance of a dummy antenna. This arrangeme with switching has been incorporated in a signal generator operatin from 100 kilocycles to 24 megacycles with six sets of coils (outside the attenuator). The piston is moved by a rack and pinion, such th the scale of attenuation occupies the circumference of a large dial. Th scale is divided uniformly and marked in decibels below one volt. Th output of the movable attenuator coil is conducted through a flexib coaxial cable.

Two principal advantages of mutual inductance attenuators over capacitance attenuators are as follows:

(1) The detuning reaction of the output circuit on the input circuit decreases with the square of the attenuation, instead of with the first power as in capacitance attenuators. This permits greater output voltage for a given permissible variation of frequency and output impedance.

(2) The input and output circuits need not be grounded to the attenuator shield. This simplifies the grounding problem, and permits the output coils of two attenuators to be connected in series for two-signal tests such as described in the 1933 Report of the I. R. E. Standards Committee.

In some respects the performance of capacitance and mutual inductance attenuators is quite different from that of resistance attenuators. If the output circuit is tuned by a load circuit, the voltage measured across its terminals is higher than the attenuator scale would indicate, although the internal voltage in series with the output circuit is correct. The results are not misleading if the output reactance is considered a part of the load circuit, as for example, where this reactance is used as part of the reactance of a dummy antenna. Otherwise, an experimentally determined correction can be applied to the output scale. The rate of attenuation is independent of this effect. In mutual inductance attenuators, the pick-up coil may resonate with a harmonic of the oscillator. The harmonic content of the terminal voltage then becomes much greater than normal, and may even affect the observed output voltage. This effect may be minimized by adding across the output coil a circuit having substantial dissipation at the resonant frequency of the pick-up coil.

The continuously variable piston attenuator, combined with convenient means for changing from one frequency range to another, tends to increase materially the speed of operation of multirange signal generators. This is an important advantage in making the large number of observations required in the design and testing of multirange receivers.

The early broadcast and short-wave receivers had the same general arrangement as the broadcast receivers. In order to change ranges, the user had to change a set of plug-in coils. This simple solution of the design problem was not acceptable to the average broadcast listener. In the first improvement the coils for the various ranges were mounted on the chassis and a gang switch was used for selecting the desired frequency. The structure was expensive and occupied considerable space. The size of the tuning system was objectionable because it re-

quired long leads, which coupled to other circuits and which constitute a large part of the inductance of the tuned circuit for the highest fre quency range. The lead inductance was likely to be variable in produc tion.

Placing all the coils for one transformer on a single coil form simplified the problem somewhat, but when a tuned radio-frequenc amplifier was added, this simplification was insufficient. Mountin the coil switch close to the coils to make the leads very short, adde to the difficulty of soldering the connecting leads between switch an coils.

Fig. 7 shows a four-range coil and switch unit which overcomes mos of the difficulties. The coil and switch are both mounted on the on

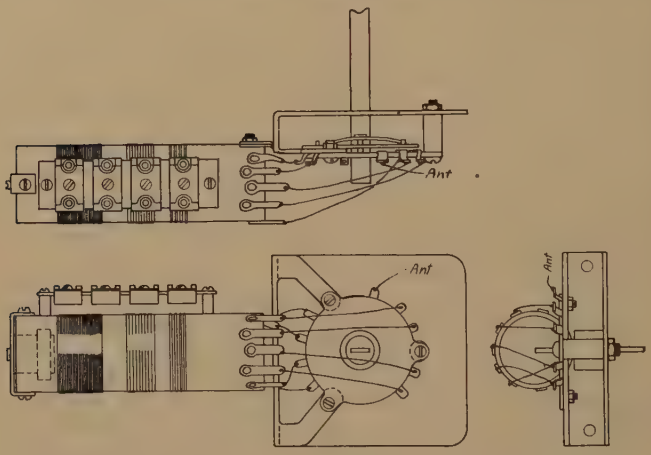


Fig. 7—Circuit preceding intermediate-frequency amplifier.

bracket. Each unit may be mounted vertically on the chassis besid the tuning condenser, or horizontally under the chassis with the switc under the tuning condenser. After all the units are mounted, the shaf of all the switches is inserted. On the coil form, the three short-wav secondaries are solenoids, the lowest inductance coil being next to th switch. The broadcast secondary is a multilayer coil inside the far en of the form. The diameter of the form is one inch. It is used in a two inch shield can. The advantages of this assembly are:

(1) The wiring is simplified. The coil and switch can be wired as subassembly, outside the chassis where all terminals are easily access ble. A defective unit may be replaced easily by simply sliding out th switch shaft and unsoldering three or four wires. The number of lon leads around the bottom of the chassis is reduced.

(2) The lead inductance is greatly reduced by the close proximit

of switch and coils. This unit is particularly well adapted to an arrangement wherein the coils in their shields are mounted horizontally under the chassis in such positions that the switch units come directly under their respective sections of the tuning condenser, thereby minimizing the length of all leads in the tuned circuits. This reduces the coupling to near-by circuits, especially at the highest frequencies. The concentration of inductance in the coil facilitates obtaining the desired coupling to it, especially in the oscillator circuit, and also simplifies the production problem of coil matching.

(3) Mounting the padding condensers inside the shield can reduces their lead inductances and shields them against undesired couplings.

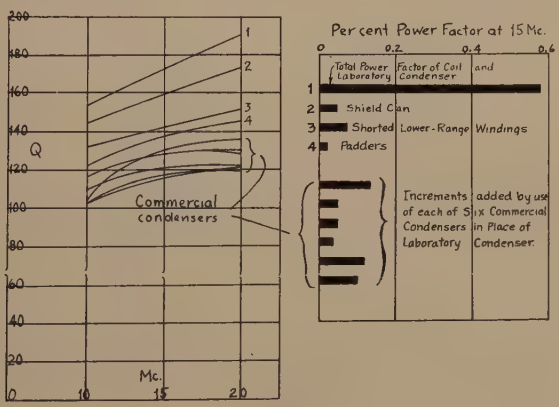


Fig. 8

Fig. 8 shows the effect of various factors on the "Q" of the coil of lowest inductance of Fig. 7. Curve 1 shows the "Q" of the coil alone, tuned by a laboratory condenser of very small dissipation. Curve 2 shows the reduction due to an aluminum shield can two inches in diameter. Curve 3 shows the further reduction due to the other coils, in position and short-circuited. Curve 4 shows the further reduction due to the padding condensers, in position along one side of the coil form. The lower curves show the further reduction due to the substitution of various commercial tuning condensers. The chart of Fig. 8 shows the contribution to the "power factor" of the tuned circuit, which is made by each of these factors.

There are two general arrangements for switching the secondary coils of the various frequency ranges, as follows:

(1) A tapped coil may be used, with provision for shorting out the unused sections.

(2) Individual coils may be used for each frequency range.

A typical circuit diagram for the tapped coil arrangement is show in Fig. 9. It is customary to include "followers" on the switch, as shown in order to short the unused sections individually and thereby to min mize the undesired absorption effects at the natural frequencies of th larger unused coils. The parallel padders should be across the particula sections of the coil with which they are associated, rather than be re turned to ground; moreover, they should be so mounted that the capa itance of the padder frame to ground is as low as possible. The reaso for these requirements is that it is usually desired to decrease the fre quency ratio of each tuning range progressively from the broadcas band to successively higher ranges, in order to facilitate tuning in th higher ranges. Moreover, it is practically necessary, from a commerci

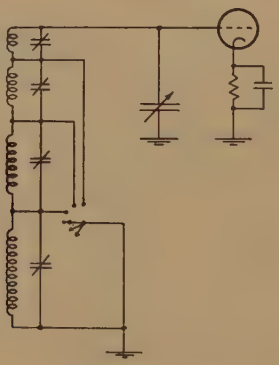


Fig. 9

point of view, to cover the entire broadcast band in a single rang Therefore, the smallest total parallel capacitance should be in circu when the entire coil is in use. If the padders returned to ground, th maximum padding capacitance would be in circuit under this conditio A disadvantage of the tapped coil arrangement resides in the fact th the alignment adjustments for the various ranges are not independen which necessitates aligning the various ranges in a definite orde beginning with the highest range.

The other general arrangement is shown diagrammatically in Fi 10, in which all of the coils have a common low potential end. In ord to avoid absorption dips in the response curves, it is necessary to sho circuit the coils of higher inductance than the coil in use at any pa ticular setting of the range switch. This requirement cannot be obviat by placing the individual secondaries in separate shield cans, becau the absorption circuits are substantially coupled to the circuit in u by the small capacitance existing between the switch contacts a

etween the leads to the switch. If the requirement of shorting the nused coils is met, all the coils may be wound on the same form. In nany cases it has been found possible to design the switch so that no dditional switch sections are required to accomplish the required horting. This arrangement has the two advantages that the tuning ange of each range is determined solely by its individual padders, vithin the limitations imposed by the tuning condenser, and that each ange can be aligned entirely independently of every other range. Its rincipal disadvantage is the additional switching required to short he unused coils.

The absorption effect mentioned above with reference to Fig. 10 s illustrated by the curves of Fig. 11. The measurements were made on

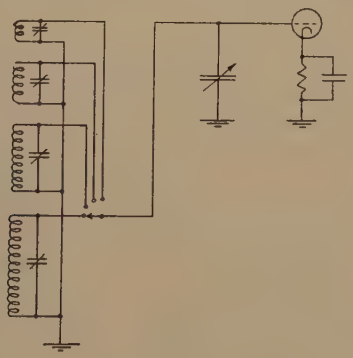


Fig. 10

he coil for the frequency range 10–23 megacycles, while the coil for he frequency range 4–10 megacycles was left unshorted. The only ther coil on the form was a helical wound broadcast coil, which was horted. A coupling capacitance of approximately three micromicro- arads existed between the high potential ends of the low inductance econdaries. Aside from the direct loss occasioned by the presence of he absorption dips, it is evident that the over-all response in a receiver s still further reduced because of the considerable misalignment that ccurs on both sides of the absorption frequencies. Experience has hown that such dips as those shown in Fig. 11 are quite capable of topping the oscillator over an appreciable frequency range, when ney occur in connection with the oscillator coils. The curves of Fig. 11 lustrate two different types of absorption dips. The more prominent ip occurs at the resonant frequency of the unshorted coil, and most of ne coupling is capacitive. The other dip is caused by the slight induc- ve coupling between the coil in use and the short-circuited broadcast

coil. In the latter case a standing wave is set up on the short-circuit broadcast coil, with voltage nodes at the ends of the coil. It is inte esting to note that shorting the middle coil removes both of these dip the reason is that the short-circuited middle coil acts as an inducti shield between the coil in use and the broadcast coil, thereby great diminishing the inductive coupling between them.

It seems to be well established that the best compromise perfor ance in all-wave superheterodyne receivers is secured by using a re tively high intermediate frequency, in the neighborhood of 450 ki cycles. It is difficult enough at best to secure good image ratios in t

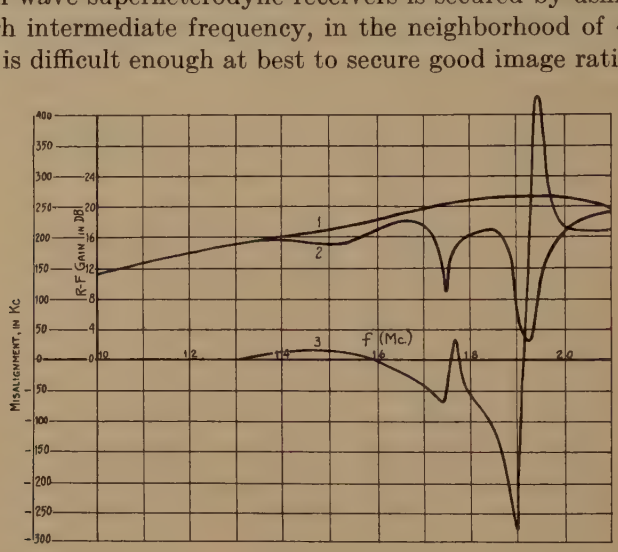


Fig. 11

high-frequency ranges and the use of a lower intermediate frequen makes the problem that much more difficult, as well as complicati the alignment processes in production. If the two principal respon frequencies are close together, the aligner is continually confront with the necessity of choosing which is the desired signal frequency a which the image frequency, with the consequent possibility of error.

It has been found that higher image ratios than are obtainab with a single tuned circuit are necessary to secure interference-fr high-frequency reception. This factor, plus a desire to secure bet signal-to-noise ratios, has led to a growing use of at least one stage radio-frequency amplification ahead of the modulator tube in ranges. The additional selectivity obtained thereby requires th correspondingly greater pains be taken to keep the various radi frequency circuits in accurate alignment. Conventional radio-frequen coupling circuits operate satisfactorily at the higher frequencies,

though the gain obtainable is not as great as at broadcast frequencies.

In view of the inherent difficulties of reducing stray couplings in radio-frequency amplifiers at very high frequencies, the unit assembly described above offers very substantial advantages. The compactness of the assembly, the short, well-shielded leads, the shielded padders, and the well-isolated ground returns make this system very stable compared to arrangements of previous types.

In order to secure the full advantages of a high-frequency radio-frequency amplifier, it is necessary that the radio-frequency gain be as

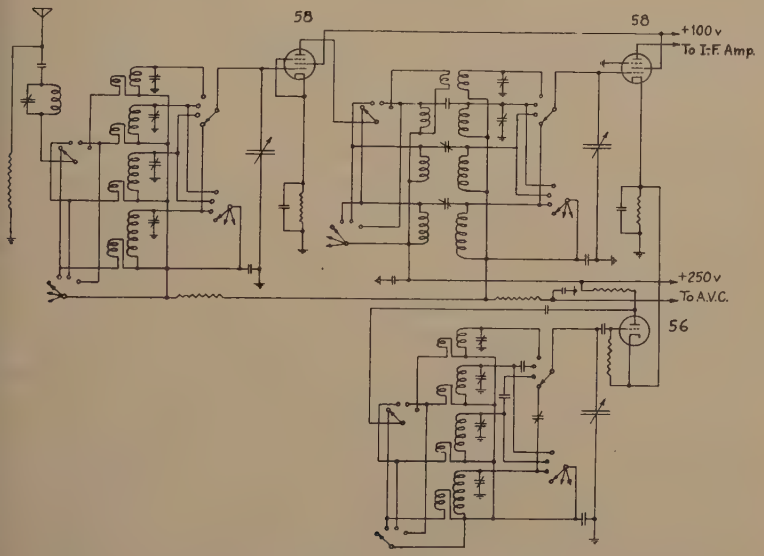


Fig. 12—Circuit preceding intermediate-frequency amplifier.

high as possible; it has been found that, in the range 10–25 megacycles in combination with an antenna-to-grid gain of two to six decibels, a radio-frequency stage gain of fourteen to eighteen decibels will reduce the equivalent noise side band input from a value of several microvolts to about a microvolt or less. Moreover, the image selectivity is very noticeably improved. This improvement is usually most noticeable when listening to broadcasting in the six-megacycle band, where the image falls in the near-by amateur band.

Fig. 12 shows the circuits preceding the intermediate-frequency amplifier in a typical well-designed superheterodyne receiver designed to receive on all frequencies from 0.53 to 23 megacycles. Four overlapping tuning ranges are used. The trap between the antenna and the antenna switch is tuned to the intermediate frequency, to minimize

interference due to signals on this frequency. Aiding inductive ar capacitive coupling from the antenna to the first tuned circuit is em ployed to obtain relatively high and nearly uniform gain to the fir grid in each range. The primary coils for the inductive coupling hav very few turns.

The capacitive coupling is due to a common condenser in the groun return leads of antenna circuit and tuned circuit. A similar condens is connected in the radio-frequency amplifier tuned circuit to maintai the alignment. The latter condenser is slightly larger because hig inductance primary coils are used in the amplifier, which partly corre the alignment in the same manner. The usual series condenser in th oscillator is made smaller than would otherwise be required, thereb contributing more to the feedback in the oscillator.

In all except the highest frequency range, the radio-frequenc amplifier transformer has primary coils tuned below the tuning rang capacitively coupled to the tuned secondary circuits. In the two low frequency ranges the coupling condensers are also used as padder This combination of expedients tends to equalize the gain in adjacer frequency ranges.

Three unit assemblies according to Fig. 7 are used, each with th general circuit arrangement of Fig. 10. In addition, all unused coi which have greater inductance than the coils in use in the tuned circui are shorted. All the unused primary coils are shorted, which is n always necessary.

The coöperation and assistance is gratefully acknowledged of oth staff members of the Hazeltine Corporation laboratories. The math matical theory of piston attenuators of the types described wa developed by Mr. Harold A. Wheeler. Professor Alan Hazeltine co tributed valuable suggestions with reference to the piston condens attenuator. Early signal generators using these attenuators we designed and built by Messrs. Harold M. Lewis and Madison Cawei Credit for the unit assembly of coil and switch is due to Mr. J. Kel Johnson.

Discussion

J. F. Dreyer, Jr.[1]: It seems desirable to add a few comments to the fir part of this paper which deals with "piston" attenuators. The discussion of the devices, summarized in Figs. 1 to 7 and attributed to Mr. H. A. Wheeler, is excellent one but does not give sufficient indication of their merit.

An attenuator of the type illustrated in Fig. 3 was made by the writer 1929 at the Atwater Kent Company. It was used and improved by Dr. Tra and later by Mr. C. A. Apker. We called it a "trombone" attenuator and fou it to have the following advantages over the resistance type:

[1] RCA Manufacturing Company, RCA Radiotron Division, Harrison, New Jersey.

First, very high voltages can be obtained with low power oscillators, thus cilitating image response measurements in superheterodynes. Second, it is mple and cheap to construct and calibrate. Third, it is free from sliding-contact oises present in many resistance type attenuators.

The Harnett and Case paper indicates that the coaxial coil type of mutual nductance attenuator may be used with calculated scales as a primary standard. he writer's experience has been that because of mechanical simplicity this evice is admirably suited for factory use. In fact many hundreds of them have een and are so used. Because they are comparatively cheap it is good practice o provide in factory test stands a separate attenuator for each different fre- uency of test signal. The attenuator may be calibrated by checking low attenu- tion points with a vacuum tube voltmeter. Then since the attenuation scale so ccurately follows an exponential law the remainder of the scale can be relied pon. This was determined in our work, wholly by experiment. We, therefore, re glad to see the mathematical formula presented at this time.

Proceedings of the Institute of Radio Engineers
Volume 23, Number 6 *June, 193*

HIGH FIDELITY RECEIVERS WITH EXPANDING SELECTORS*

By

Harold A. Wheeler and J. Kelly Johnson

(Hazeltine Corporation, Jersey City, New Jersey)

Summary—*A high fidelity receiver for general use requires means for con tinuously expanding or contracting the resultant band width of all the carrier selec tors, in order that the best compromise between fidelity and selectivity may be chose for any given operating conditions. The expanding selector ("XPS") arrangemer may be adapted for either unsymmetrical or symmetrical expansion of the resonanc curve. Arrangements are described and the relative merits are discussed for both kind of expansion. A superheterodyne receiver is described, which has a preferred form c symmetrical expanding selector, as well as other advantageous features. A tuning an expanding mechanism is described, in which the expansion is adjustable by movin the tuning knob in the axial direction. The mechanism includes an interlock whic permits the operator to tune the receiver only when the band width is contracted. Th operator is thereby constrained to follow the correct procedure of first tuning wit maximum selectivity, and second, expanding to improve the fidelity to the exte permitted by noise or adjacent channel interference.*

LABORATORY work on the improvement of radio receiver fidel ity has been carried on with steadily increasing intensity durin the past five years. The lower costs of component parts and th improved tubes have made it possible to manufacture a very hig grade receiver in the present upper price bracket. In this field, ther has been no substantial progress in extending the upper limit of audi frequencies reproduced by commercial receivers. The demand fo single channel selectivity has been a major impediment to such prog ress, since the outer side bands are greatly attenuated by highl selective circuits.

High fidelity in radio reception requires the uniform reproductio of a wide range of audio frequencies over a wide range of loudness free of any wave form distortion and background noise arising in th broadcast system. The increasing interest in this subject as a whole i evidenced by the many recent publications and demonstrations relat ing thereto. This paper is devoted entirely to only one of the severa special problems arising in the design of high fidelity receivers. Tha problem is the extension of the upper limit of audio-frequency repro duction, as limited by the selectivity requirements.

* Decimal classification: R361.2. Original manuscript received by th Institute, February 18, 1935. Presented before Ninth Annual Convention, Phil delphia, Pa., May 30, 1934.

A high grade receiver for general use must have available sufficient selectivity to receive any one of the many stations from which reception can reasonably be expected by the user. If this receiver is to be classed as a high fidelity receiver, it must also have means for utilizing the maximum usable audio-frequency range, considering the incidental interference and noise limitations. It is not sufficient that the receiver may be capable of high fidelity reception only under ideal conditions such as are seldom met in the field. The best compromise between greatest selectivity and highest fidelity must be available to the user.

Expanding selector arrangements have been devised to meet these requirements. They include means for continuously adjusting the side band acceptance of the receiver over a wide range. This adjustment is made substantially independent of the tuning over the broadcast band. The circuits for this purpose are mainly associated with the intermediate-frequency amplifier of a superheterodyne receiver. The three-letter designation "XPS" has been adopted for expanding selectors.

The adjustable nature of expanding selectors makes available new possibilities for improving selectivity, as well as fidelity. The present nonadjustable selectors involve a severe compromise between selectivity and fidelity, each being limited mainly by the other. The expanding selector relieves the necessity for this compromise on the part of the manufacturer, and places the responsibility in the hands of the user, who may at will shift the compromise to suit operating conditions.

For present purposes, the uniform reproduction of audio frequencies up to 7000 cycles is considered adequate for high fidelity broadcast reception. This upper limit permits filtering out the 10,000-cycle beat notes between carriers on adjacent channels, and also permits filtering out the major part of the "monkey-chatter" caused by side bands of interfering signals on adjacent channels. Uniform reproduction up to 7000 cycles represents about an octave improvement over the best receivers now available.

The reproduction of the higher audio frequencies does not require the acceptance of the outer side bands on both sides of the carrier. Nor is it practicable to separate the side bands entirely and utilize one side band exclusively. It is practicable to utilize all of one side band and the inner part of the other side band, with due attention to equalizing the fidelity of the system.

When the band width of an expanding selector is contracted for greatest selectivity, double side band reception is always preferred. Further side band acceptance for higher fidelity can then be obtained by expanding the selector on one or both side bands. Expansion on

only one side band is designated "sesquiside band" reception, becau approximately all of one side band and half of the other side band a utilized.

All expanding selector circuits can be classified as symmetrical unsymmetrical, according to whether the expansion is effected on bo side bands or only on one side band. Before describing circuits in bo classes, some of their relative advantages and disadvantages shou be understood. Table I shows such a comparison in tabular form.

TABLE I

Comparison of Symmetrical and Unsymmetrical XPS Circuits

Characteristics when expanded	Symmetrical Class (double side band reception)	Unsymmetrical Class (sesquiside band reception)
Complicity of operation	One option =amount of expansion	Two options =amount of exp sion and choice of side band
Dependence of fidelity on the tuning	Noncritical, tuning center of band to carrier	Critical, tuning edge of band carrier
Selectivity possible with given fidelity	Better when comparable interference is on both sides of desired carrier	Better when major interfere is on only one side of desi carrier
Distortion of modulation envelope	No distortion because side band symmetry is maintained	Slight distortion because band symmetry is disturb especially at higher audio f quencies
Noise (static, circuits, tubes) relative to signal	Minimum	About three decibels above minimum
Design limitations	Better for fidelity	Better for selectivity

Expanding selectors of the unsymmetrical class must be designe to give the user an option as to which side band he wishes to favor b expansion. This additional option, which may be exercised unskillfull is a disadvantage of unsymmetrical circuits.

Symmetrical circuits generally require less care in tuning, becau the fidelity is not a critical function of the tuning. When unsymmetric circuits are expanded, a predetermined point on one side of the selec band must be tuned quite accurately to the carrier. The greater a curacy required is another disadvantage of the latter.

When the desired signal is subject to major interference on on one adjacent channel, the unsymmetrical circuits have a considerab advantage, assuming that the user expands on the clear side ban Great selectivity against such interference can be secured, even whe the selector is fully expanded.

When the desired signal is subject to like interference or noise o both side bands, the symmetrical expanding selectors give less inte ference or noise relative to the signal. The reason is found in the b havior of the signal rectifier toward side bands and noise. The audi frequency rectified signal output due to both side bands is six decibe

bove that due to only one side band, because the two components of he output are of equal frequency and are additive in phase. The audio-requency rectified noise output due to both side bands is only three ecibels above that due to one side band, because the two components re unrelated in frequency and phase. The increase of noise due to nsymmetrical expanding is therefore about three decibels greater han the increase of noise due to symmetrical expanding, assuming hat the signal fidelity is the same in both cases.

Unsymmetrical expanding produces a nominal amount of envelope istortion, because it disturbs the side band symmetry. The amount f distortion is not likely to be noticeable if both inner side bands are tilized for modulation below 1000 cycles, and if the expanding does ot accentuate the desired outer side band more than six decibels elative to the carrier. The most obnoxious result of such distortion is ne production of cross-products or beat notes between various com-onents of modulation. This effect is minimized by the use of a linear ectifier such as a well-proportioned diode circuit.

There is not a closed case for either class of expanding selectors. ymmetrical circuits are capable of being designed to give a greater efinement of performance with respect to all properties except selec-vity. Unsymmetrical circuits are capable of better performance here interference on only one adjacent channel comprises the most evere restriction on the usable fidelity. Either class of circuits, with electors contracted, can be designed to have great sensitivity and electivity, useful for reception from distant stations.

The further discussion deals first with unsymmetrical circuits and econd with symmetrical circuits. A complete receiver is then de-cribed, and also a novel mechanism having a single knob for both uning and expanding adjustments.

In the circuits to be described, the expanding operation generally as a slight effect on the gain of the receiver at the carrier frequency. utomatic volume control is always provided, designed to maintain ne amplified carrier voltage constant during expansion or contraction the expanding selector. This function must be substantially in-ependent of the signal modulation which can be assured by the use a well-proportioned diode rectifier circuit for automatic volume ntrol.

All forms of expanding selectors are preferably adapted to the termediate-frequency circuits of superheterodyne receivers, so that e expansion can be made substantially independent of the tuning. ne radio-frequency selective circuits preceding the frequency changer e designed to have a nearly uniform resultant band width, sufficient

to pass a fourteen-kilocycle band without appreciable attenuation
The center of this broad band remains tuned to the desired carrie
while the intermediate-frequency selectors may be expanded on on
or both side bands.

A major requirement in the design of expanding selectors is "cor
sistency of expansion." When the user is adjusting from the contracte
condition to the expanded condition, there must be a continuousl
increasing expansion of the audio-frequency range. At the same time
there must be no substantial attenuation at any intermediate audi
frequencies relative to the lower audio frequencies. In terms of th

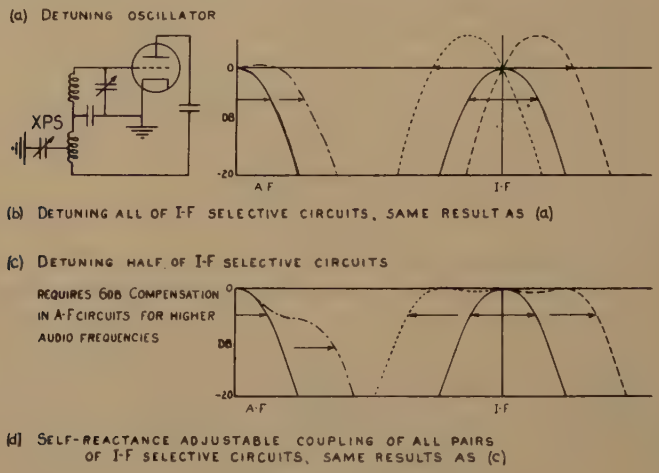


Fig. 1—Unsymmetrical XPS circuits.

fidelity curve, the expanding adjustment must shift the curve generall
outward and upward, and must not cause appreciable recession of an
part of the curve during any phase of the adjustment. This consistenc
requirement places definite restrictions on the audio-frequency rati
of expansion obtainable with any given form of expanding selecto
This is discussed further in connection with symmetrical circuits.

Fig. 1 indicates the performance of several forms of unsymmetric
expanding selectors. In each case, the effect of the expanding selecto
on the fidelity is determined by the variation of the average acceptanc
of both side bands, as a function of the modulation frequency. Th
average is a vectorial average, with due respect to the relative pha
of carrier and side band acceptance. In most practical cases, the simp
average is a fair approximation.

Fig. 1(a) shows a simple arrangement for unsymmetrical expansio
The intermediate-frequency amplifier is made fairly selective, witho

eans for expansion. Auxiliary means are provided for detuning the cillator frequency a few kilocycles in either direction, the amount of tuning being made nearly independent of the main tuning adjustent. The oscillator circuit shown has this provision in the form of a nall adjustable condenser coupled to the main tuned circuit by comned negative mutual inductance and a common condenser. The tter are so proportioned that the frequency shift due to the auxiliary ndenser is nearly the same when the oscillator is tuned for reception any frequency in the broadcast band.

In Fig. 1(a) the consistency requirement necessitates a round-top sonance curve in the intermediate-frequency circuits. The envelope stortion caused by detuning limits the usable expansion to a ratio about two to one. This limitation on the performance is partly unterbalanced by the extreme simplicity of this arrangement, which s only one adjustable element for expansion.

Fig. 1(b) indicates the same results obtainable alternatively by tuning all the intermediate-frequency selective circuits simultaously. The large number of adjustments makes the use of this rangement unnecessarily expensive, since the performance is the me as that of Fig. 1(a).

Fig. 1(c) shows unsymmetrical expansion by detuning half of the termediate-frequency selective circuits. This reduces the number of justable elements to two or three, and gives very good performance. ne usable expansion ratio is about three to one, as limited by the nsistency requirement. The envelope distortion is minimized because ere is negligible accentuation of the accepted side band relative to e carrier. The expanded fidelity is upheld by compensation in the dio-frequency circuits, to the extent of six decibels at the higher equencies for which the expansion is effective.

The unsymmetrical detuning arrangements of Figs. 1(a), (b), and) all give maximum carrier gain when contracted, which is generally desirable feature. Arrangements in which the coupling is adjustable r expansion, which are still to be described, give maximum carrier in when the coupling is optimum, which generally corresponds to intermediate adjustment of expansion.

Fig. 1(d) indicates unsymmetrical expansion by coupling the termediate-frequency selective circuits in pairs by adjustable self-actances. The number of adjustable elements and the resulting exnsion are the same as in Fig. 1(c), for approximately the same permance. The effect is to vary the tuning of all circuits, and simulneously to vary the coupling, holding one peak nearly in tune with e carrier.

Fig. 2 shows eighteen of the many possible circuits for accomplis
ing unsymmetrical expansion by the use of adjustable self-reactan
coupling between two tuned circuits. In every example, there are tv
kinds of coupling, one an adjustable self-reactance and the other
fixed mutual or self-reactance. The mean coefficient of the adjustab
self-reactance coupling is equal and opposite to that of the fix
coupling. Therefore the resultant coefficient of coupling is adjustab
continuously between a positive maximum and an equal negati
maximum. Each maximum corresponds to full expansion on one si
band.

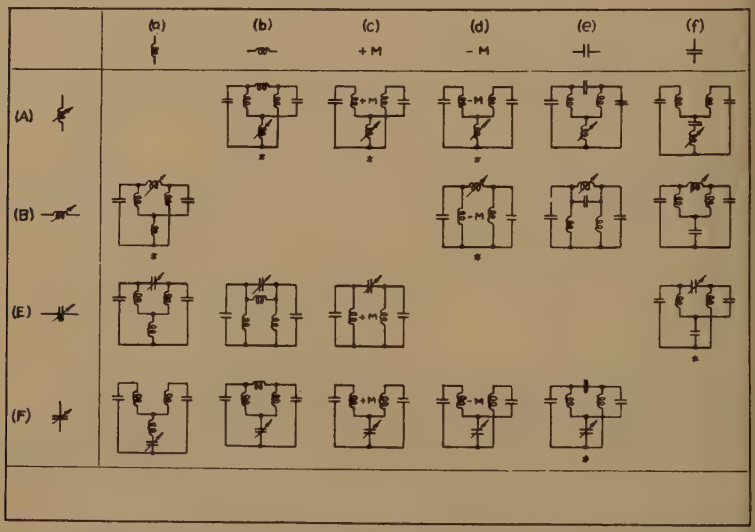


Fig. 2.—Unsymmetrical XPS circuits with adjustable self-reactance couplin

Of the many possible coupling schemes using combinations of fix
and adjustable reactances, two general types are distinguished
their different performance characteristics. The first type is illustrat
by the seven examples marked with an asterisk in Fig. 2. This ty
uses a combination of couplings whose reactances vary similarly wi
frequency. The effect secured is simply an adjustment of the resulta
value of coupling between the two tuned circuits, from a negati
maximum through zero to a positive maximum. Since an appreciab
resistance component of coupling usually accompanies the reactan
coupling, the net coefficient of coupling does not ordinarily pa
through zero. Such resistance coupling may be desirable, providing
is so small as not to interfere with the desired reactive effects when t
resultant reactance coupling is substantial.

The second type is illustrated by the remaining examples in Fig. 2. This type uses a combination of couplings whose reactances vary oppositely with frequency. The effect secured is similar to that of the first type, except that the amount of coupling varies with frequency, and approaches zero at a frequency not far removed from the resonant frequency of the tuned circuits. When this "trap" frequency is on one side of the resonance curve, it may have the desirable effect of improving the sharpness of selectivity on that side. When the trap frequency is equal to the resonant frequency of the tuned circuits, the signal carrier may be trapped out. When this condition exists, the signal is badly distorted.

TABLE II

A Pair of Similar Tuned Circuits (R, L, C)

Center of resonance curves:

$$\omega_0 = \frac{1}{\sqrt{L_0 C_0}}$$

Frequency variable:

$$x = \frac{2\Delta\omega}{\omega_0} << 1$$

Power factor:

$$p = \frac{R_s}{\omega_0 L_0}$$

Coupling coefficient:

$$k = \frac{M}{L_0}$$

Detuning coefficient:

$$h = \pm\frac{\Delta L}{L_0} \text{ or } \pm\frac{\Delta C}{C_0}$$

+ for one circuit
− for other circuit

Expanding coefficient

$$\sqrt{k^2 + h^2}$$

Shape of resonance curves:

$$\frac{E}{E_0} = \frac{1}{\sqrt{1 + \frac{x^2[x^2 + 2p^2 - 2(k^2 + h^2)]}{[p^2 + (k^2 + h^2)]^2}}}$$

Envelope of resonance curves:

$$\left(\frac{E}{E_0}\right)_{max} = \sqrt{1 + \left(\frac{x}{2p}\right)^2}$$

Shape of resonance curves multiplied by inverted envelope:

$$\frac{E}{E_0} = \frac{1}{\sqrt{1 + \left\{\frac{x[x^2 + 3p^2 - (k^2 + h^2)]}{2p[p^2 + (k^2 + h^2)]}\right\}^2}}$$

Three equal peaks at

$$x = 0, \pm\sqrt{(k^2 + h^2) - 3p^2}$$

From the preceding discussion, it is apparent that there is considerable latitude in the choice of a selector for unsymmetrical expansion and that the most suitable arrangement is that which has the greatest number of desirable characteristics and the fewest undesirable characteristics, in view of the contemplated service.

Since symmetrical expanding selectors are generally susceptible of greater refinement with respect to reduction of noise background and distortion, and with respect to improvement of audio-frequency fidelity, a more careful analysis of such circuits is warranted. Table II is a mathematical summary of the more interesting selective properties of a pair of similar tuned circuits. The carrier frequency is taken equal

to the mean of the natural frequencies of the two circuits. Thr parameters of the circuits are taken into account, of which p denot the power factor or dissipation, k denotes the coefficient of mutu inductance coupling, and h denotes the coefficient of symmetrical d tuning of the circuits, one above and one below the mean frequency carrier frequency. A pure mutual inductance is a simple fundament type of coupling which can be adjusted to produce symmetrical e pansion. The independent variable x is double the relative departu of the frequency from the mean. Therefore x is proportional to t modulation frequency in the analysis of side band acceptance.

The shape of the resonance curve depends only on the power fact and on the expanding coefficient, which latter is the quadratic su of the coupling and detuning coefficients. Therefore the expansion independent of the relative values of coupling and detuning, althou the variation of gain with expansion depends on the relative valu The use of a level automatic volume control operated by the carri has the effect of maintaining the carrier output uniform during e pansion. In analyzing on this basis the shape of the resonance curv the center point of the curve is taken as unity. Having reduced all the family of resonance curves to unity at the mean frequency, t family has a peak envelope curve which is the inverse resonance cur of a single tuned circuit whose power factor is $2p$. Multiplying t resonance curves by the inverted envelope, the result is a family curves which have three equal peaks and a nearly flat top when e panded. This resultant is obtainable in practice by the use of a thi uncoupled circuit, tuned to the carrier, having double the power fact of each of the tuned circuits of the adjustable pair.

Fig. 3 shows several families of half resonance curves based on t analysis of a pair of tuned circuits. Fig. 3(a) shows the relative ga and the shape of the familiar curves in which the coupling is t variable parameter. Fig. 3(b) shows the corresponding family wi symmetrical detuning as the variable parameter. Fig. 3(c) shows t same families reduced to unity at the mean frequency. This is t effect of a level automatic volume control operated by the carrier the mean frequency. Only the shape of the curve is important, a that is determined entirely by the ratio of the expanding coefficie to the power factor. The dotted curve is the envelope of this famil and happens to be also the inverted resonance curve of a single tun circuit having a power factor of $2p$.

Fig. 3(d) is the same family multiplied by the resonance curve such a single tuned circuit. The result is the expansion of x in the ra of four to one at six decibels down, with negligible violation of t

nsistency requirement. Further expansion causes appreciable in-nsistency. In this combination, when expanded, a pair of coupled rcuits and an uncoupled third circuit produce a result which is perior to that of a single section, nondissipative, constant-K filter. oreover, the expansion of the band width of the three-circuit com-nation can be effected by adjusting only one parameter, the mutual ductance of the pair of tuned circuits. The selectivity is the most at reasonably could be expected from three tuned circuits, especially hen expanded.

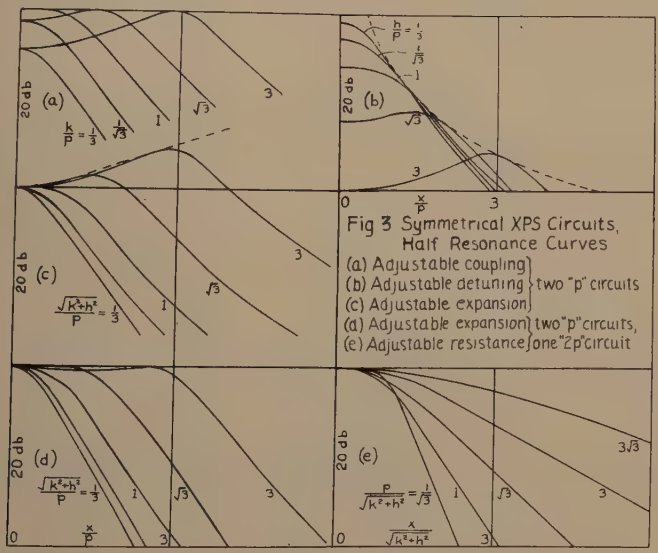


Fig. 3

For comparison, Fig. 3(e) shows several curves of the same family, t plotted with the power factor as the variable parameter. This ult would require adjusting simultaneously three resistors of the ree respective tuned circuits. The expansion ratio can be increased thout limit, but the selectivity is very poor for the expanded con-ion. It is to be noted that over the inner portion of the range the quirement of consistency is violated and the fidelity might actually nd poorer with increase of power factor. The practical disadvantage attempting to secure improved fidelity by the adjustment of re-tance in such circuits with fixed coupling is thus graphically exposed.

From among the various forms of expanding selectors, the three-cuit combination with adjustable mutual inductance has many nts in its favor. Two such combinations, having a total of six

intermediate-frequency selective circuits, is very well adapted for u in a high fidelity receiver. Expansion is then effected by simultaneou increasing the mutual inductance in each of two intermediate-f quency transformers.

Fig. 4 shows the circuit of a complete receiver having the s circuit symmetrical expanding selector with mutual inductance pansion. This function is secured by three double-tuned intermedia frequency transformers. Two of these transformers have mutual ductance adjustable by a common control. The third transformer h both of the 2*p* circuits for flattening the envelopes of the other t transformers. The 2*p* circuits are loosely coupled to give the effect

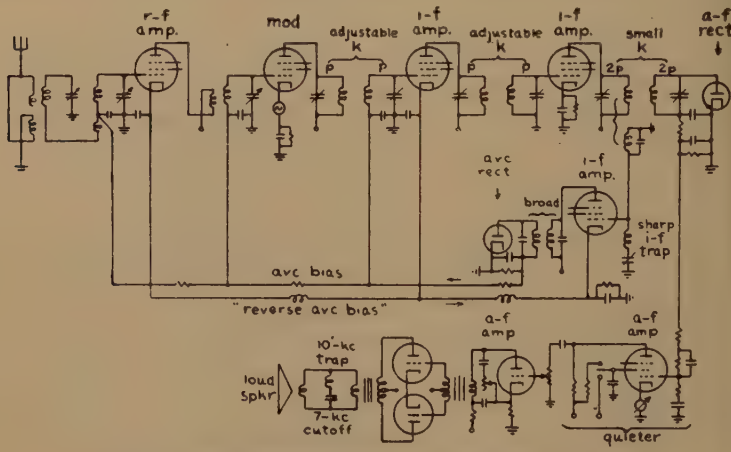


Fig. 4—Complete receiver with expanding selector.

two uncoupled circuits, as required by the mathematical analys The nominal expanded band width of the flat top is fourteen kilocycl and the expanding ratio is about five to one at six decibels down.

Otherwise, the receiver is essentially a carefully designed sup heterodyne, with several improvements not yet found in commerc receivers.

The three selective circuits preceding the frequency changer designed to have uniform gain and band width over the broadc band. The resultant band width of these three circuits is fourte kilocycles at four decibles down. This slight side band attenuation compensated in the audio circuits. The adjacent channel selecta of these circuits is seven decibels, which is ordinarily adequate avoiding cross-modulation, since the gain preceding the frequer changer is less than thirty decibels maximum, and is subject to duction by automatic volume control.

The frequency changer should be designed to minimize cross-
odulation and oscillator drift. It is especially important that the
cillator frequency be made independent of the automatic volume
ntrol action, because the receiver has great selectivity available.
The automatic volume control is performed by an auxiliary am-
fier and diode rectifier circuit. The action of this circuit is modified
a sharply tuned trap circuit. This trap is designed to reduce the
ntrol action to normal when the receiver is tuned exactly to the
gnal carrier, but to cause excessive control action when the carrier
detuned slightly. This is a very satisfactory scheme for producing
aximum loudness when the receiver is exactly tuned. Some such
rangement is practically necessary in a receiver having available
ch selectivity, in order to reduce the tendency toward abnormally
id and harsh reproduction when the tuning is a few kilocycles off
e signal frequency. This necessity is increased by the use of a high
elity audio system.

An additional important advantage of this trap circuit is that it
uses interfering signals on adjacent channels to be subject to ex-
ssive control action. In this manner, the presence of substantial
terference causes a substantial reduction in the loudness of repro-
ction. The user is thereby encouraged to contract the selector until
e loudness of the desired signal is restored, free of interference.

A properly designed diode rectifier provides level automatic volume
ntrol, free of fluctuation due to signal modulation. The leveling is
cured by means of a common cathode bias resistor for the controlled
mplifiers and the auxiliary amplifier. The result is a reverse control
tion on the latter, decreasing its cathode bias and thereby increasing
gain in proportion to the requirements for greater automatic volume
ntrol bias.

The audio rectifier is carefully designed and is operated at a fairly
gh carrier voltage input level, about ten or twenty volts. The direct-
rrent load conductance is reduced to two micromhos, and the added
dio-frequency load conductance is held down to one tenth this value,
cept at high audio frequencies where the modulation is very small.
he result is negligible distortion for modulation up to unity.

A simplified quieter circuit is employed to reduce further the loud-
ss when the receiver is not exactly tuned to the signal carrier, or
hen interference is present. A pentode audio amplifier is operated
th excessive resistance in the plate circuit, so that the gain is very
w for zero grid bias, and increases to a maximum at a certain negative
lue of grid bias. This action, combined with that of the sharply
ned trap, gives very good quieting action to the extent of about

thirty decibels. A switch is provided for inserting resistance in t screen lead and thereby cutting out the pentode quieting action desired. A visual tuning meter is connected in the pentode catho lead to indicate precisely when the receiver is in tune with a carri The meter deflection is nearly independent of signal intensity, sin the rectified signal carrier applied to the pentode is subject to le automatic volume control.

A tone control is provided to meet conditions frequently observ at the present time, due to the prevalence of unsatisfactory micropho location relative to the performers. The tendency in arranging orchestra, for example, is to locate the high pitch instruments mu too close to the microphone. Fairly high fidelity can still be secur at the receiver by shading off the medium high audio reproducti about six to ten decibels. Some tone control action may be desirab also where circumstances require music to be reproduced much belo its normal loudness. Therefore the tone control, properly used, m still be desirable as a practical expedient.

All audio amplifiers are designed for class A operation, becau the high fidelity greatly reduces the tolerance toward distortion, a generally causes the user to be satisfied with less power.

The selectivity of the receiver in the expanded condition is i sufficient for discriminating against adjacent channel interferen even when the latter is only moderate. The adjacent channel discri ination is only about twenty decibels when the selector is fully e panded, and increased to sixty decibels when fully contracted. obtain further discrimination for expanded operation, a ten-kilocyc trap is provided. This trap is preferably connected in the voice c circuit, for two reasons. First, there is some benefit in filtering out distortion components or noise above 7000 cycles, arising in any pa of the entire receiver. Second, it is possible to utilize, as part of t filter, the voice coil inductance and the leakage inductance of t output transformer. As a result, the trap can be designed to ha negligible effect below 7000 cycles and still to discriminate at lea twenty-five decibels at ten kilocycles. Further discrimination is less utility, because the usable expansion is then limited by interferi side bands overlapping the desired side bands.

Fig. 5 shows fidelity curves on the six-circuit expanding selec of this receiver. The coefficients of coupling are adjustable in the ra of five to one, between six-tenths optimum and three times optimu The audio band is thereby adjustable from about 1500 to 7500 cycl There is less than one decibel violation of the requirement of consi ency of expansion, as indicated by the slight interweaving of the t

outer curves. The dotted lines show the effect of adding the ten-kilocycle trap in the voice coil circuit, when the selector is fully expanded.

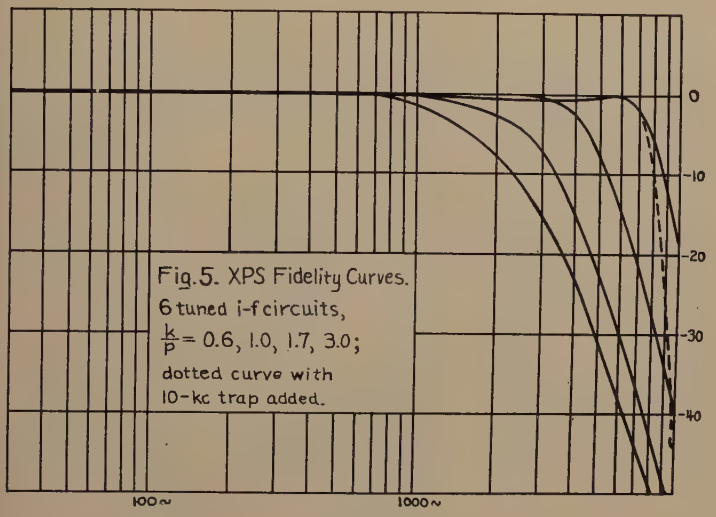


Fig. 5

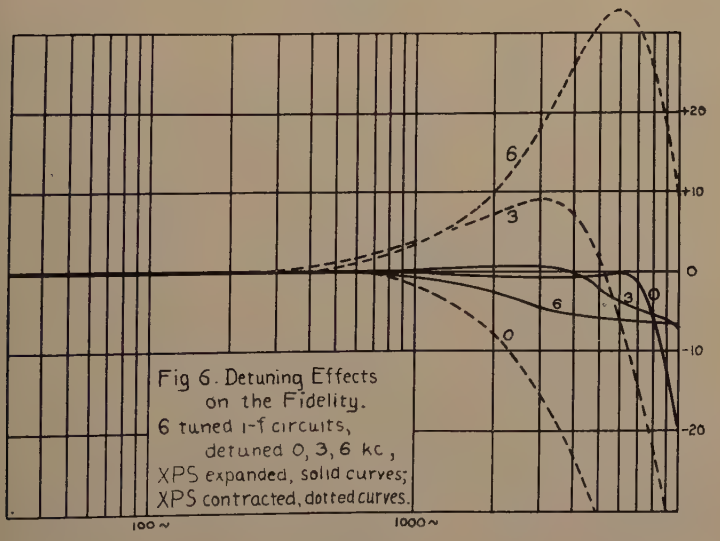


Fig. 6

Fig. 6 shows the effects on the fidelity, due to detuning the receiver when the selector is expanded or contracted. The solid curves show that the fidelity is materially decreased by slight detuning when the

selector is expanded, but this effect is not of such a nature as to soun very objectionable. The dotted curves show the extremely detriment effect of slight detuning when the selector is contracted. In the latte case, the reproduction becomes harsh and distorted, because the sid bands are greatly accentuated relative to the carrier. In the absenc of suitable precautions, the loudness is greater under these abnorm conditions. The sharp trap in the automatic volume control circui and the pentode quieting circuit, contribute to decreasing greatly th loudness when detuned, and thereby avoiding these undesirable effect

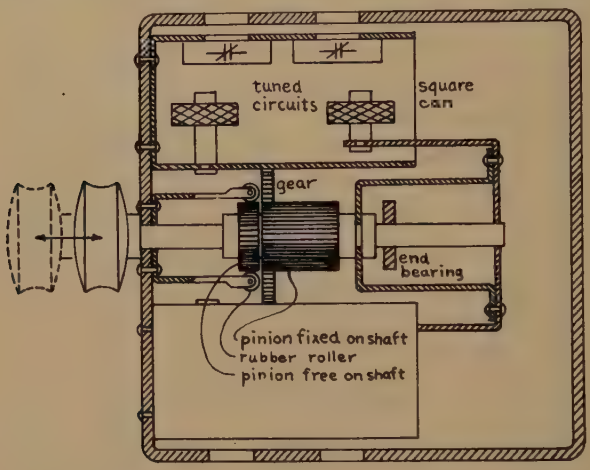


Fig. 7—XPS interlocking mechanism, bottom view.

In view of the effects of detuning, it appears that the user woul be unable to tune the receiver accurately with the selector expande although the trap in the automatic volume control circuit would b of some assistance. If the user were subsequently to contract th selector, any inaccuracy of tuning would become apparent and th observed effect of the expanding adjustment would be erratic. appears that the logical procedure in tuning with an expanding selecto is first to tune accurately with the selector contracted, and then t expand as far as permitted by the receiving conditions. This procedu also has the advantage that the user hears every station while tunin and therefore does not get the impression that his receiver is insensitiv or nonselective.

Fig. 7 shows a simple mechanism utilizing axial motion of th tuning knob for adjusting the expansion of the expanding selector. A interlocking mechanism is also provided which permits the user t tune the receiver only when the band width is contracted. The us

is thereby constrained to follow the correct procedure of first tuning with maximum selectivity, and then expanding to improve the fidelity to the extent permitted by noise or adjacent channel interference.

The diagram shows the bottom view of an arrangement well adapted for use in a small remote control box. The tuning shaft carries a frame on which is mounted one coil of each of two intermediate-frequency transformers. Moving the knob outward from the panel increases the coupling in these transformers and thereby expands the selector. The same shaft carries a long pinion fixed on the shaft and an adjacent short pinion free to rotate on the shaft. The long pinion is always engaged with a gear on the main tuning shaft. There are two small rubber rollers pressed against the sides of one pinion or the other. The shaft is shown in the position for tuning, and the rubber rollers are on the free pinion, so they offer no resistance to turning the shaft for tuning the receiver. After the receiver is tuned, the knob is then pulled out for expanding. When the knob is pulled out, even for partial expansion, the rubber rollers grip the long pinion and prevent turning the shaft, thereby preventing the user from detuning the receiver. Since the operations of tuning and expanding are both performed by one knob in one hand, rapid manipulation is easy. This interlocking mechanism for tuning and expanding has met with considerable approval during the time it has been demonstrated in the laboratory.

It is desired to acknowledge the valuable contributions which have been made to this development by the other members of the engineering staff of Hazeltine Corporation. Among those who have taken an active part in this project are Messrs. W. A. MacDonald, D. E. Harnett, N. P. Case, J. F. Farrington, and C. K. Huxtable.

Proceedings of the Institute of Radio Engineers
Volume 23, Number 6 *June, 19*

ACOUSTIC TESTING OF HIGH FIDELITY RECEIVERS*

By

Harold A. Wheeler and Vernon E. Whitman
(Hazeltine Corporation, Jersey City, New Jersey)

Summary—*The broadcast listener desires the illusion of being present in t auditorium or studio where the sound is being produced. Therefore the sound hea by the listener in a living room should have essentially the same qualities. In broa casting, the studio reverberation, the microphone technique, the loud speaker charc teristics and the living-room reverberation are among the more important facto which must coöperate in obtaining the desired illusion. The latter two factors a evaluated by testing the loud speaker in representative living rooms. The test micr phone is located respectively at each of three stations selected to be representative listening points. Acoustic fidelity curves for these stations are superimposed on single record. An acoustic recorder is described which has been developed for aut matically tracing each curve in about three minutes. Curves are reproduced whi show the effect of frequency wobbling in integrating the reverberation.*

THE design of high fidelity receivers for sound reproduction the living room is a problem very different from the problem sound reproduction in the auditorium. The latter problem h received the most attention, in connection with talking motion pictur and the recent auditory perspective demonstrations. Reproduction the living room has more utilization than all other forms of loud speak reproduction, and yet the essential nature of this problem appears have received very little attention. This deficiency is abundant demonstrated when the present broadcasting is received and repr duced by a carefully designed high fidelity receiver, reproducing fro 50 to 7000 cycles without appreciable distortion.

An encouraging sign is the steadily increasing attention being pa to the high fidelity problem as a whole, and especially as it exists broadcast transmission and reception. This activity is evidenced b the many recent publications and demonstrations on this subject, ar by the improvement of some of the equipment in broadcast tran mitters.

The incentive for continued improvement is limited by the unive sal use of receivers whose fidelity leaves a great deal to be desired. is an exceptional receiver which gives nearly uniform reproductio even over the five and a half octaves between 75 and 3500 cycles. T high fidelity receivers are expected to extend the audio-frequency ran an octave higher and half an octave lower, and also to improve t

* Decimal classification: R261.3. Original manuscript received by t Institute, February 18, 1935. Presented before Ninth Annual Convention, Phi delphia, Pa., May 30, 1934.

uniformity throughout the range. The result will be a seven-octave receiver adequate for excellent reproduction of broadcast programs.

This paper is directed to the problem of testing the ability of broadcast receivers to give uniform reproduction of sound, over the required audio-frequency range, when operated under normal conditions in the living room. The first requirement is a correct statement of the problem.

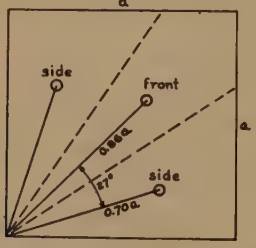
Very few engineers seem to appreciate that the listener desires the illusion of being present in the auditorium or studio, and that this illusion requires the sound reverberation characteristics of the latter, even though the reproduction is heard in the living room having much less reverberation. This is most important in the case of music, less important in the case of speech. Optimum reverberation is just as important as perfect rendition in the production of very good music. Optimum reverberation in a large auditorium has a mellowing effect on the music, giving both listeners and performers a satisfaction which cannot be equalled by a similar performance in a small room, regardless of the acoustic treatment of the latter. Therefore the first requirement of good broadcasting of music is a large studio with optimum reverberation. Even though there may be no audience, optimum reverberation is a necessity, because the performers should hear their own music under most favorable conditions, and because the music requires the mellowing effect of reverberation.

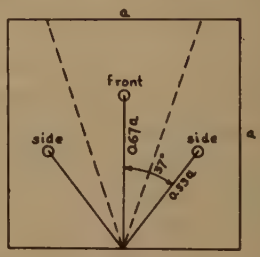
There is considerable reverberation in the living room, but generally less than optimum. A double reverberation effect is produced when the studio pick-up receives considerable reverberant sound in the studio. This requires that each individual source of reverberation have less than optimum effect on the reproduction. Therefore the studio pick-up should slightly favor the direct sound as against the reverberant sound. The ribbon microphone has directional properties useful for this purpose. The microphone should be located about as far from the performers as the listener would choose to sit if he were present in the studio. One of the most common faults in present technique is placing the microphone too close to the soloist or the high pitched instruments.

When the studio and performers and microphone pick-up are once arranged to meet these requirements, the problem of high fidelity reproduction in the living room is greatly simplified. The sound in all parts of the living room should be substantially the same as the sound at the microphone. Thus stated, the problem is perfectly definite, and the various steps toward its solution follow in a logical succession. The further discussion is directed to the testing procedure and equipment which have been developed for easily and quickly determining the sound distribution in the living room, produced by a loud speaker in a given position in the room.

The distribution of sound in the living room is influenced mainl by the directional characteristics of the direct radiation and by th reverberation in the room. The latter tends to mask the former, makin the sound distribution more nearly uniform. The reverberation als causes irregular interference patterns due to multiple reflection. Th ear seems to tolerate this effect as a necessary adjunct of the desire reverberation, and therefore frequency wobbling is employed as means of averaging this effect in the fidelity curves. The average effec of reverberation is not a critical function of the living room acoustics and therefore representative observations can be made in a representa tive living room.

Since the test microphone is the substitute for the ear in the testing it should be pressure actuated, not velocity actuated. The sound pres sure and sound velocity do not, in general, have the same frequenc distribution, especially near the speaker at low frequencies.





(a) Loud speaker in corner position. (b) Loud speaker in side-wall positio

Fig. 1—Microphone stations for acoustic tests.

Since the tests are intended to include the average effects of rever beration on the sound distribution, the microphone should be non directional in all three dimensions.

These two requirements dictate the use of a pressure actuate microphone of very small dimensions. Therefore a special crysta microphone is used, comprising two very small sound cells mounte close together in a wire cage slightly larger than a one-inch cube. It field calibration is uniform within one decibel between 50 and 700 cycles, and is independent of any reasonable length of shielded cabl between microphone and amplifier. Ten to forty feet of cable may b used.

The direct radiation of a loud speaker depends on the speaker an the speaker mounting, and also on the adjacent walls and floor of th room. The speaker and speaker mounting are predetermined factors The floor is a predetermined factor for console speakers but not fo

table models. A console speaker is usually located in the corner of the room or against a side wall, in which case the effect of the walls is fairly well predetermined for either position. Therefore a console speaker is tested in one of these two positions, as indicated in Fig. 1.

The general interference pattern due to reverberation is critically dependent on room acoustics, and therefore cannot be taken into account in the testing. There are two factors affecting reverberation which can be taken into account. These are the height of the ceiling and the height of the listener's head above the floor. The ceiling height is generally about nine feet, and the height of the listener's head is generally about three feet above the floor. Therefore the test microphone is suspended at a height of three feet in a room whose ceiling is about nine feet high.

The fidelity curves must show not only the average sound distribution in the room, but also the probable departure from the average, since the latter is determined mainly by the loud speaker, its mounting and its location in the room. Every curve has its peculiarities, according to the location of the microphone. Three curves taken at suitable points in the room are adequate for most purposes. The preferred microphone stations for these three curves are based on the diagrams in Fig. 1. For each position of the loud speaker, a square room is divided in three sectors of equal area centered on the speaker, and the center of gravity of each sector is determined. This procedure locates three preferred microphone stations relative to the loud speaker. Three such stations may then be used in all tests, even though the shape of the room and its dimensions may vary considerably. The latter do not critically affect the more important properties of the fidelity curves. On the basis of a room 14 or 15 feet square, about 2000 cubic feet, the distances from speaker to microphone stations are chosen for most tests. With the speaker in the corner position, a front distance of 12 feet and side distances of 10 feet are used, with a side angle of 27 degrees. With the speaker in the side-wall position, a front distance of 10 feet and side distances of 8 feet are used, with a side angle of 37 degrees. These microphone stations appear to form an adequate basis for testing the distribution of sound in the living room, in so far as the tests are capable of yielding valuable information on the behavior of the loud speaker under operating conditions.

Fig. 2 is a photograph of the complete acoustic recorder which has been developed especially for use in this work. Careful attention has been paid to securing maximum convenience, reliability, and speed of operation. The equipment is a rugged self-supporting unit which is easily transportable for field tests. The power is obtained entirely from

the sixty-cycle lighting circuit. All cathodes are indirectly heated, a
all rectifiers are followed by voltage regulators, to minimize the effe
of line voltage fluctuations. Each unit has its individual power supp
circuits.

The audio-frequency generator is the lowest of the four main uni
The frequency dial is motor-driven through a gear train. Any one
six speeds can be selected quickly by a simple gear-shifting operatic
The time for sweeping over the audio spectrum ranges from two-thir
to eight minutes, according to the speed chosen.

Fig. 2—Acoustic recorder.

The frequency wobbler is located on the bottom, and is also mo
driven. The wobbling condenser turns five times a second. The amou
of frequency wobbling is instantly adjustable by a switch in six st
from ± 10 cycles to ± 400 cycles.

The crystal microphone suspended on its cable is seen in the up
left corner of the photograph.

The first unit at the top is the microphone amplifier, using t
262A nonmicrophonic triodes with indirectly heated cathodes.

The second unit is the logarithmic amplifier-rectifier. This ampli
has automatic volume control operating on amplifier tubes having
exponential form of gradual cut-off. The rectifier output is amplifie

several milliamperes. The amplified current is made proportional to the input variation in decibels, over a range of fifty decibels.

The third unit is a photographic recorder comprising a rugged oscillograph element and a recording drum driven in synchronism with the audio-frequency dial. The oscillograph element is the movement from a portable milliammeter, with the pointer removed and a very small mirror attached to the armature. The drum carries sensitive paper for slow records or film for fast records. A switch is provided for selecting a twenty-, thirty-, or fifty-decibel range for the full width of the oscillographic record.

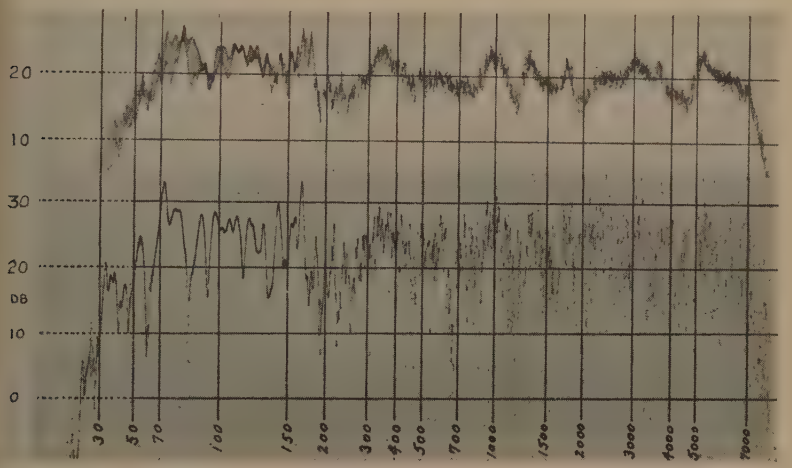


Fig. 3—Lower curve—Interference effects of reverberation in living room, loud speaker in corner position, eight-minute record.
Upper curve—Same as below, with addition of frequency wobble not exceeding ± (10 cycles+5 per cent).

The time constant of the photographic recorder and associated circuits is only about one-tenth second. The time lag is so small that the fluctuations caused by the wobbler can be recorded if desired. This time lag is comparable with the time required for the reverberation to build up in the living room.

The noise background in this apparatus, including the living-room sounds, corresponds to about one milliwatt in the loud speaker. Therefore records can be made accurately with fifty milliwatts or more in the loud speaker.

The records to be shown were taken on an audio system including a special cone speaker operated with about one watt in the voice coil.

The lower curve of Fig. 3 is a photographic record taken at slow speed to show the full effects of reverberation. The loud speaker was

in the corner position of the living room and the test microphone
at the front station. In the upper part of the frequency range,
anomalous dispersion of the curve is observed more than ten deci
above and twenty decibels below average.

The upper curve of Fig. 3 is a similar record taken with the addit
of frequency wobbling, in order to average the reverberation effe
The oscillograph traces the cycle of wobbling to some extent, as in
cated especially by the shaded band appearing on the left side of
curve.

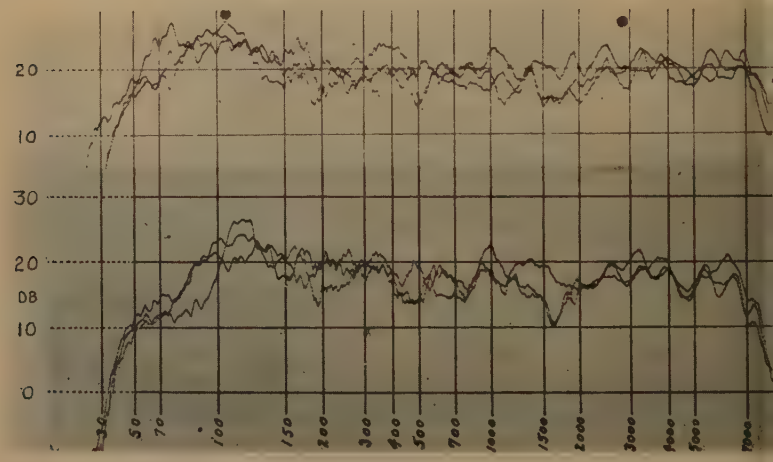


Fig. 4—Upper curves—Fidelity curves, loud speaker in corner position. Th
minute records.
Lower curves—Same as above, except loud speaker is in side-wall posit

The amount of frequency wobbling is always held within the a
trary limit of ten cycles plus five per cent above and below the m
audio frequency. Usually the wobbling is varied between ± 10 cy
and ± 200 cycles over the audio range.

Fig. 4 comprises photographic records taken on the same l
speaker according to the preferred routine. In addition to the wobbl
a smoothing circuit is added to filter out the fluctuations during
wobbling cycle. Three curves are superimposed on the record for e
position of the loud speaker in the living room. For each set of th
curves, the test microphone is stationed according to the diagr
shown in Fig. 1. Each curve is recorded in three minutes, so that a se
three curves can easily be made in fifteen minutes.

The upper curves of Fig. 4 show the fidelity curves taken with
loud speaker in the corner position, while the lower curves show

corresponding curves taken with the loud speaker in the side-wall position. These curves indicate the average fidelity over the area of the living room, and also give an indication how much departure from the average may be expected throughout the room.

It is apparent that the corner position is more favorable, because the frequency range is wider, especially at the lower limit, and also the three curves are less subject to irregularities from all causes. The reason for these advantages resides in the smaller angle into which the speaker is required to radiate from the corner position.

These curves must not be confused with curves taken outdoors, or with curves taken in a dead room. Such curves have some value in the design of loud speakers, but do not form a satisfactory basis on which to judge the final performance of the reproducing system. Curves taken in the living room are more irregular because they include the effects of many factors that are absent in tests made under specially chosen artificial conditions. These many factors are always present, however, during reproduction in the living room.

Experience indicates that curves such as in Figs. 4 give a satisfactory indication of the fidelity of an audio system or a complete radio receiver, under conditions representative of normal operating conditions.

In conclusion, it is desired to acknowledge the valuable assistance of Messrs. W. O. Swinyard and R. E. Sturm in carrying forward the work on this project.

Proceedings of the Institute of Radio Engineers
Volume 23, Number 6 *June, 1*

HIGH QUALITY RADIO BROADCAST TRANSMISSION AND RECEPTION*

By
Stuart Ballantine
(Ballantine Laboratories, Inc., Boonton, New Jersey)

PART II—THE RECEIVING SYSTEM†

THE transmitting section of the broadcast system, which was c sidered as extending from the microphone to the transmitt antenna, was discussed in Part I† of this paper. In Parts II a III we shall follow the same systematic program in discussing the ceiving system, which we regard as extending from the receiving tenna to the sound field of the loud speaker. The present Part II be particularly devoted to the technique of measuring the over-all p formance of broadcast receivers, a subject of considerable importa which must underlie the successful development of a high quality ceiver.

The receiving system may be divided broadly into two parts: electrical part, or receiver proper, and the electro-acoustic part, or lo speaker. It is also desirable to include a third element—the *auditoriu* This term is not used in its conventional restricted sense as designat a large hall or meeting place, but in a more general sense to design the room or place where the receiver is installed and listened to, gardless of size. The *auditorium* is included as part of the receiv system because it exercises an important influence upon the acousti performance of the receiver and should be regarded acoustically a part of the loud speaker system.

11. Measurement of the Electro-Acoustic Fidelity of Broadcast Receivers[37]

To avoid interruption in the later discussion it will be desirable interpose at this point some account of the technique of measuring over-all performance of broadcast receivers.

* Decimal classification: R550. Original manuscript received by the Instit April 16, 1935. Presented before New York Meeting, November 8, 1933; Ph delphia Section, December 7, 1933; Franklin Institute, Philadelphia, Februar 1934; and Boston Section, April 20, 1934.

† Part I of this paper was published in Proc. I.R.E., vol. 22, pp. 564–6 May, (1934).

[37] Although previously unpublished, the material in this section was sented four years ago in a paper entitled: "Technique of Loud Speaker So Measurements," Philadelphia Section, Institute of Radio Engineers, May 1931; at the Annual Convention, Chicago, June 5, 1931; and at the New Y meeting of the Acoustical Society of America, May 3, 1932.

Measurements of the important electrical performance indexes of the receiver, such as fidelity, selectivity, sensitivity, noise, cross-talk, harmonic distortion, etc., have been standardized and their technique is well established. Such measurements have now become a matter of routine in the development of broadcast receivers and in the control of the quality of the manufactured product. These electrical measurements are largely concerned with the receiver chassis itself and leave out of account the loud speaker. For certain of the measurements enumerated the loud speaker may very properly be ignored, but it should certainly be included in any final estimate of the over-all performance of the receiver, particularly with regard to fidelity and distortion.

We shall use the term *electro-acoustic fidelity* to designate the relation between the acoustical pressure in the sound field and the modulation frequency of the signal applied to the antenna circuit of the receiver, and the term *electrical fidelity* to designate the relation between the *electrical* output and the modulation frequency.

Measurements of the electro-acoustic fidelity are essentially of an acoustical nature and are complicated by a multitude of factors which are not present in the much simpler measurement of electrical fidelity. There is, largely on this account, a considerable divergence in the views of technicians in this field as to the proper methods of procedure. No universally acceptable technique has been evolved and the little standardization that has been attempted is merely experimental and tentative.

The technique to be described in the following paragraphs, developed during the past ten years and based on a study of the fundamental acoustical problems involved, has been found convenient and accurate for engineering and development purposes.

For the measurement of over-all (electro-acoustic) fidelity the obvious procedure is to introduce into the artificial antenna circuit a standard modulated signal and to determine the relation between the modulation frequency and the sound pressure.

The sound pressure frequency characteristic will vary from point to point in the sound field, especially indoors; the question therefore arises as to the best point to place the measuring microphone. For example, most loud speakers are directive and the response at the higher frequencies falls off on either side of the axis. Several schemes have been proposed for avoiding this difficulty. One method, at present much in vogue, consists in rotating the microphone in front of the loud speaker in a plane 45 degrees to the horizontal, the idea being to obtain average values over a region which is supposed to represent the

"listening region." My experience with this method, however, has led me to prefer a fixed microphone for the following reasons:

(1) Nothing is measured definitely. About all that the results show is what an observer might hear if he were being rapidly rotated in front of the loud speaker. There is no way of predicting from such measurements what an observer would hear in any fixed position in the sound field;

(2) This averaging process smooths out the fluctuations in the frequency characteristic and thus tends to present an illusory picture which is much too favorable; it is, indeed, about as logical to rotate the microphone as it would be for a spectroscopist to vibrate his photographic plate;

(3) The low-frequency picture is usually considerably in error due to the defective averaging which occurs when the diameter of the circle of rotation becomes comparable with the wavelength of the sound.

There may be, however, certain measurements where the rotating microphone may be useful in spite of these objections. An example is the case of measurements in a highly reverberant environment such as an average living room, where it is desired to break up the standing wave pattern.

It must be admitted, with regard to this question, that one may learn to interpret sound-pressure records taken in a variety of ways and preference for one method over another may be in the last analysis largely a matter of habit or one's philosophical predilections.

A *fixed* microphone *of the proper type*, on the other hand, permits a definite measurement of the sound pressure at that point in the sound field, which since the ear is pressure-actuated, is directly related to what would be heard by an observer similarly situated. Fundamental information may be obtained by placing the microphone on the axis of the loud speaker; after this the directivity can be determined by placing the microphone at various angles from the axis. This procedure has the advantage of giving definite information about the directivity, which cannot be obtained from rotating microphone curves. It is usually sufficient to confine the measurements to a few angles, say 0, 30, 45 degrees, and for routine testing a single curve taken at 30 degrees will give values which are fairly good averages for a listening sector extending from $+45$ to -45 degrees. When curves are taken in a living room the sound pressure varies from point to point in the room and is affected by the room as well as the directivity of the speaker so that a greater number of microphone positions are usually necessary to obtain a complete picture.

1. Automatic Frequency Response Recorder

In measurements of the electrical fidelity of the receiver chassis *per se* the fidelity curve is usually sufficiently smooth to be quickly constructed from measurements by the ordinary point-by-point method employing relatively large frequency intervals. In the case of the electro-acoustic fidelity, however, the acoustical characteristics of the loud speaker are so irregular and serrated as to require a prohibitively large number of measurements for their accurate delineation by this method. To facilitate such measurements and to avoid such time-consuming drudgery an automatic sound-pressure recorder[38] has been developed

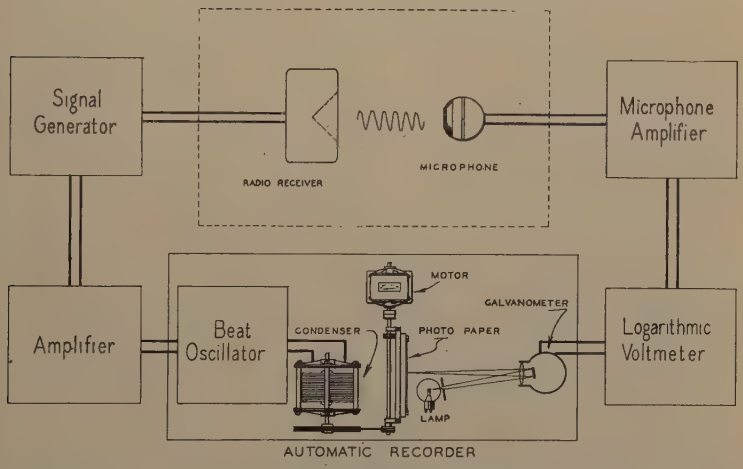


Fig. 44—Schematic diagram of apparatus for automatically recording the electro-acoustic fidelity of radio broadcast receivers.

which is capable of furnishing a complete characteristic in a few minutes which formerly required hours by the old method, and with far greater accuracy.

The fundamental scheme for automatically recording the electro-acoustic fidelity of radio receivers is shown in Fig. 44. The receiver is supplied with a standard modulated signal of which the modulation frequency is continuously variable from 50 to 10,000 cycles. The source of variable modulation frequency is a beat oscillator with which is associated a condenser having specially shaped plates, giving an accurately logarithmic relation between beat frequency and angular rotation. This provides a logarithmic frequency scale. This condenser is

[38] For a more detailed description of the recorder and its electro-acoustical applications see "A logarithmic recorder for frequency response measurements at audio frequencies," *Jour. Acous. Soc. Amer.*, vol. 5, p. 10; July, (1933), and *Electronics*, January, (1931).

rotated at any desired rate by a small variable speed motor. An extension of the shaft of the motor is mechanically geared to a platen, carrying a piece of photographic paper, and arranged to move vertically. The sound from the loud speaker is picked up by a microphone, amplified, and by means of a special device labeled "logarithmic voltmeter," converted into a direct current which is proportional to the logarithm of the sound pressure. This current operates a special high speed galvanometer provided with a mirror which moves a small light spot across the photographic paper, thus recording the amplitude of the sound pressure on a logarithmic scale.

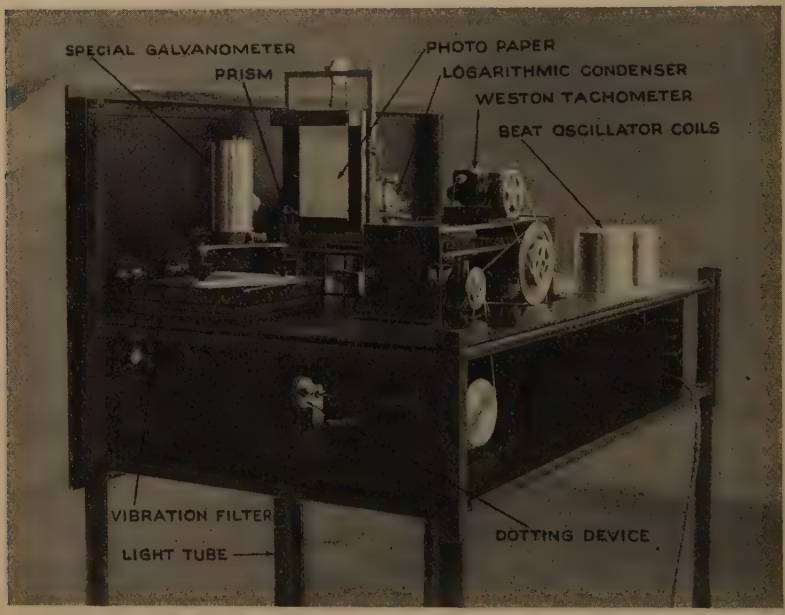


Fig. 45—Rear view of automatic frequency response recorder.

A suitable frame of coördinates is impressed upon the photographic paper by projection from a photograph plate in a separate enlarging camera. During this projection the paper is held in a frame which has been carefully aligned for registration with the platen as regards the frequency scale.

Except for the photographic processes—developing, fixing, and drying—the recording is automatic.

The speed of the platen is adjustable over a wide range and is regulated in conformity with the expected serration of the frequency characteristic. The period of the galvanometer and associated apparatus is unusually low so that an ordinary record of loud speaker response out-

doors or in a damped room can be taken in less than one minute. The records, sufficiently dry for inspection and comparison, are available in a few minutes, whereas by the point-by-point method several hours would be required.

Several curves may be recorded on one piece of paper. The results of changes in apparatus may be readily brought out by taking, on one sheet, records before and after the change, dotting one curve to facilitate recognition. Means are provided for standardizing the amplifiers so that the interval between two such records on one sheet may be as long as desired. A photographic view of the recorder from the rear is shown in Fig. 45. The accuracy with which a logarithmic frequency scale has been obtained is shown in Fig. 46.

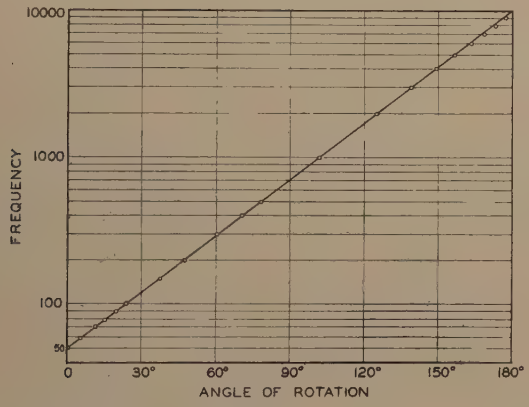


Fig. 46—Calibration of beat oscillator for frequency response recorder.

The logarithmic relation between output current and input voltage in the logarithmic voltmeter is obtained by using special variable-mu tubes having an accurately exponential relation between transconductance and control grid bias. Two amplifier stages are used, terminated by a rectifier which supplies an automatic grid bias for maintaining a constant output voltage. Over the range in which the output voltage is automatically held constant the auto grid bias is proportional to the logarithm of the input voltage. The galvanometer indicates the grid bias. The amplitude range of the present apparatus is 100× (40 decibels) which is adequate for this kind of work. The performance of the logarithmic voltmeter and the accuracy with which the logarithmic relation is obtained over this range is shown in Fig. 47; the frequency characteristic at various levels is shown at the left of the figure.

On account of the logarithmic nature of the ordinate scale a uniform decibel scale of sound pressures can be employed if desired.

This apparatus represents a considerable advance over a previou recorder, built in 1926, which employed a linear scale of ordinates an in which the curve was traced by following the indications of a pointe type meter by hand. I feel that with an increasing appreciation of th value of over-all receiver measurements, an apparatus of this kind, c an equivalent, is destined to play as important a part in routine broac cast receiver engineering and testing as does the ubiquitous standar signal generator of the present day.

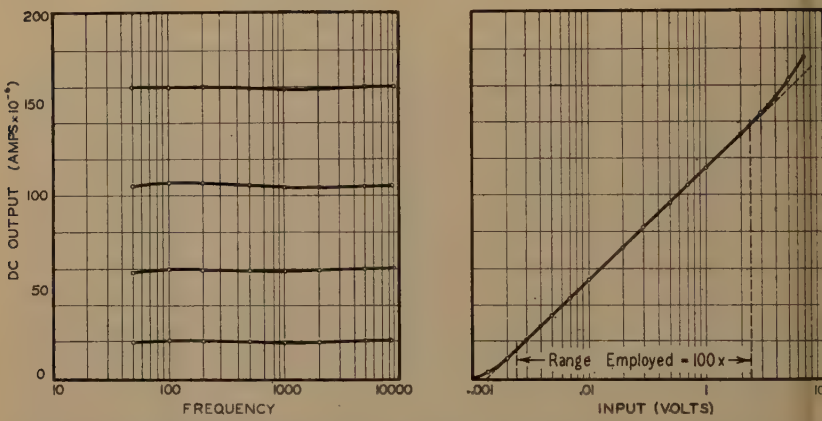


Fig. 47—Characteristics of logarithmic voltmeter; (right) direct output curre versus applied alternating input voltage; (left) direct output current vers frequency, constant input voltage.

2. Microphones

For most measurements a condenser microphone of special desig is employed. This is spherical in shape and the diaphragm is a ranged to lie in the surface of the spherical housing in order to avoi cavity resonance.[39] Sensitivity is deliberately sacrificed in the interes of stability. No measurable change in sensitivity or frequency respons has occurred during six years of use. Ordinary commercial condens microphones are likely to be too unstable for work of this charact (see Part I, Fig. 5, p. 579).

The microphone has been carefully calibrated against a Rayleig disk (wave calibration) in order that the true pressure in the sour wave may be measured. The design is such that by means of a ver simple type of equalization in the electrical circuits the frequency cha acteristic has been made uniform within one decibel from 50 to 10,0

[39] For a more detailed description of this microphone see Ballantine, Pro I.R.E., vol. 18, p. 1206; July, (1930), and *Jour. Acous. Soc. Amer.*, vol. 3, p. 31 (1932).

cycles; thus the true pressure is directly recorded and no corrections for the microphone characteristic are required. The constancy of the microphone response is checked from time to time by means of the electrostatic grille.[40] The wave calibration of the microphone should always be used in this work as the ordinary thermophone (or pressure) calibration may be in considerable error at the higher frequencies due to diffraction and cavity resonance.

The frequency characteristic of this type of microphone changes with the angle from which the sound is arriving with respect to the diaphragm (directivity effect). For this reason it is only suitable for measuring the pressure in a simple progressive wave. In a more complicated wave field in which waves may be arriving from more than one direction a microphone of this type cannot be used to measure the pressure. An example of such a sound field is that produced by a receiver in a reverberant closed space, such as a living room. In this case a special nondirectional microphone is used. This comprises a single Brush "sound cell" made from Rochelle salt crystals (for a description see Part I, p. 584 *et seq.*). The size of this crystal sound cell is so small (1/4″×1/4″) that diffraction effects are negligible for all frequencies of interest and the response is substantially the same for waves from any direction. This nondirectional microphone is used for measurements in living rooms where it is desired to measure the true pressure at a point.

Although they are frequently used for loud speaker measurements it should be emphasized that *velocity microphones are not suitable for measurements of sound pressure* except under exceptional conditions; i.e., that of a simple progressive plane sound wave. Such conditions are seldom encountered except outdoors at a distance from a simple source. Since the ear is a pressure-operated device measurements of loud speaker response with velocity microphones are meaningless. Fig. 9, Part I, shows the difference in the records of a loud speaker made with pressure and velocity microphones. Not only are the low-frequency patterns different but also near 1500 cycles, where the power is divided between the two speakers, there are important differences.

3. *Outdoor Measurements*

We come now to a consideration of the influence of the acoustical environment of the receiver and microphone upon the measurements of over-all fidelity.

The best acoustical conditions for such tests are found outdoors. The receiver and microphone should be located as far as possible from

[40] Reference 5, Part I.

all reflecting surfaces. Since clear spaces of adequate size can generally be found the chief source of embarrassment is reflection from the ground. Consider the case of a piston radiator of radius, R. The reflected wave from the ground (assuming perfect reflection) may be

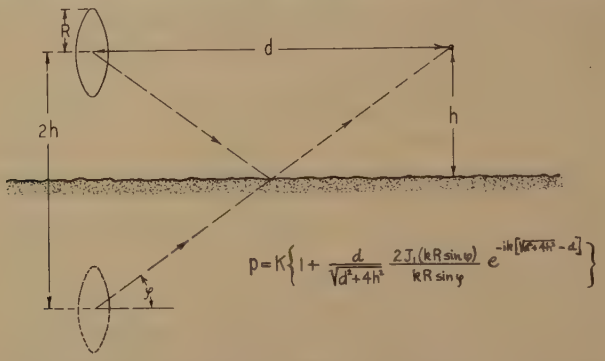


Fig. 48—Illustrating calculation of effect of reflection from the ground.

represented by a direct wave from an image piston symmetrically located below the surface (Fig. 48). Assuming that the frequency characteristic of the piston is level, and taking into consideration the directivity due to diffraction, the total pressure due to direct and reflected waves can be calculated (see formula in Fig. 48). This is plotted in

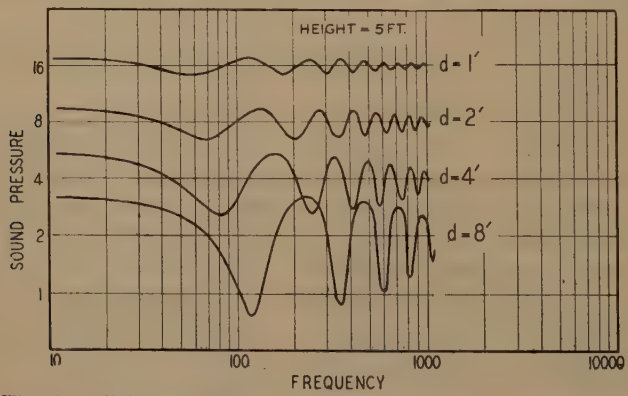


Fig. 49—Calculated effect of ground reflection on sound-pressure frequency characteristics.

Fig. 49 for a height of five feet and distances of one, two, four, and eight feet between microphone and radiator.

The effect of reflection increases rapidly as the distance between the microphone and receiver is increased, hence it is desirable to work as close to the receiver as possible. This must not be carried too far for other reasons to be considered later.

Actual experimental sound-pressure records showing the effect of height above ground upon reflection effects are shown in Fig. 50. The ordinates in each record are proportional to sound pressure but have no absolute significance; the input to the receiver was the same for each height. The depressions in the curve for a height of five feet, due

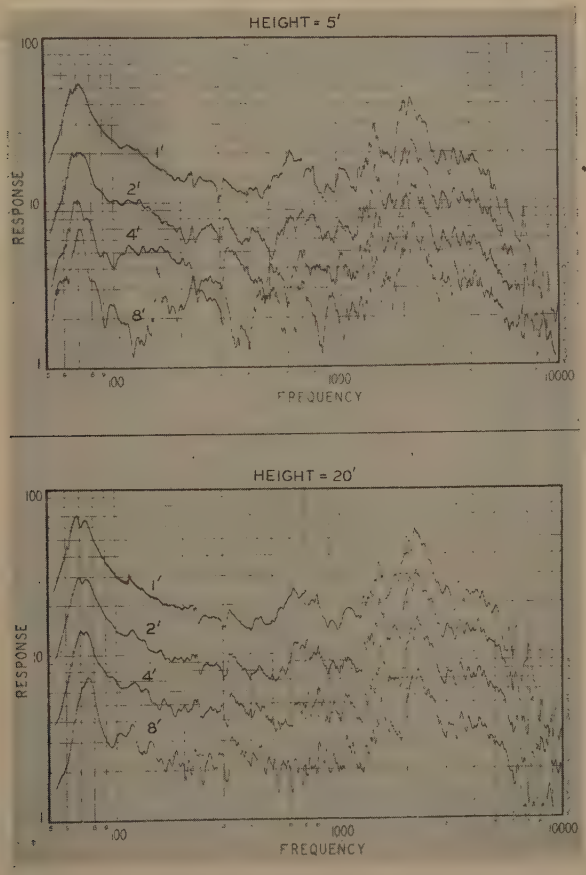


Fig. 50—Experimental outdoor sound-pressure frequency records at various heights and microphone distances.

to destructive interference between the direct wave and the wave reflected from the ground, correspond closely to those calculated and are especially noticeable at d = eight feet. These depressions have virtually disappeared for a height of twenty feet at d = eight feet. The residual higher frequency serrations in this curve are caused by reflections from a laboratory building. In general the serrations in Fig. 50 due to re-

flection from the ground are somewhat weaker than those calculatec (Fig. 49). This is probably due to the fact that the reflectivity of th ground is actually less than unity, as assumed in the calculations, an to the directivity of the loud speaker being somewhat different fro that of an ideal piston. It would seem that results of sufficient accurac for engineering purposes can be obtained with a two-foot separation a a height of five feet, but for greater separations proportionally greate heights should be used. Our standard practice is to employ heights o twenty-four feet for accurate measurements up to microphone separa tions of eight feet, and for ordinary purposes, heights of five feet for ou standard separation of two feet.

The frequencies of the minima due to reflection in Fig. 49 are od multiples of the frequency of the first minima. The frequency of th

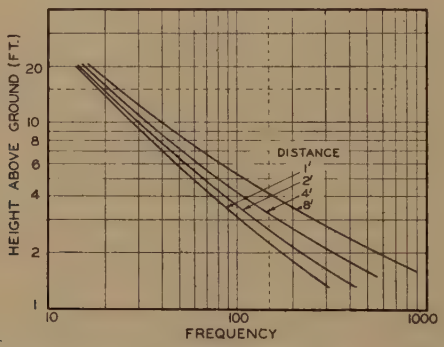


Fig. 51—Calculated frequency of first minima due to ground reflection for various heights and microphone distances.

first minima for various heights and distances are shown in Fig. 51 which is included as of possible interest in identifying suspected de pressions in sound pressure curves.

A further question which arises concerns the proper distance be tween the microphone and receiver. From the viewpoint of avoidin trouble due to reflected waves it is desirable, as we have just noticed to place the microphone as close to the receiver as possible. There ar two additional effects, however, which come into play as the distanc between the the microphone and loud speaker is decreased. Both effect are due to diffraction.

The first effect is a lowering of the high-frequency response as th distance is decreased. This is brought about by the fact that radiation from the various parts of the diaphragm get out of phase as the dis tance becomes comparable with the dimensions of the radiator and th wavelength of the sound. Assuming a circular piston radiator of radiu R the sound pressure on the axis is given by

$$p = C \sin \frac{\pi f}{c} (\sqrt{R^2 + x^2} - x), \tag{2}$$

where C is a constant, c the velocity of sound, f the frequency and x the distance. If x is large compared with R,

$$p = C \sin \frac{\pi f R^2}{2cx}. \tag{3}$$

At large distances the pressure is proportional to the frequency for a constant piston velocity. To isolate the diffraction effect in which we are interested from this normal variation of pressure with frequency

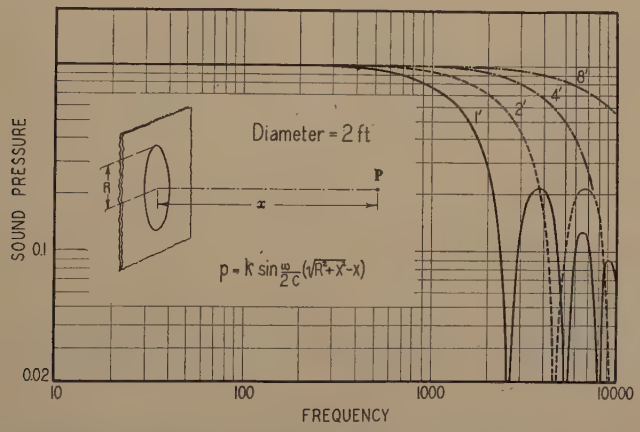


Fig. 52—Effect of diffraction upon axial sound pressure for a two-foot piston at various microphone distances.

For a piston assume that the piston velocity varies inversely with frequency so that at large distances the axial pressure is uniform with frequency. The effect is then brought out by dividing (2) by the frequency and plotting the resultant pressure against frequency for various distances as shown in Fig. 52. We see that the closer the microphone is placed to the loud speaker the sooner diffraction causes the pressure to fall off with increasing frequency.

The error due to this effect will be negligible if the distance is greater than $d^2f/1600$, where d represents the diameter of the radiating surface in feet and f is the frequency. If we wish to limit the error to two decibels the distance should be greater than $d^2f/3600$. The diameter of the average loud speaker is about nine inches. For a two-decibel error at 10,000 cycles the distance between microphone and speaker would have to be at least eighteen inches. A minimum distance of two feet can be regarded as a safe rule applicable to most radio re-

ceivers having a single loud speaker. For multiple loud speaker system greater distances are required.

There is also a second effect, likewise due to diffraction, which manifests itself as an increase in the relative intensity of the sound pressures at low frequencies as the distance between the microphone and loud speaker is decreased. This effect is connected with the baffle (or cabinet) surrounding the loud speaker.

Consider the idealized simple case of a piston radiator in a spherical baffle. The sphere completely encloses the back of the piston and prevents any radiation from the rear. The effect of such a baffle can be found by an application of the principle of reciprocity according to which the pressure at a distant point P due to vibration of the piston in the spherical surface with unit velocity is the same as the pressure

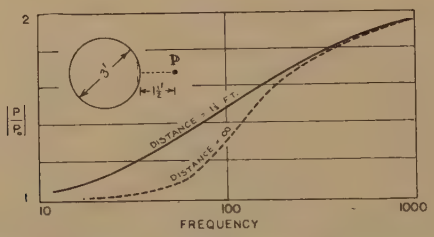


Fig. 53—Sound-pressure doubling due to spherical baffle; sound-pressure ratio versus frequency for microphone distances of 1½ feet and infinite distance diameter of baffle = 3 feet.

which would exist at that point of a rigid spherical surface due to an acoustical source at the point P. The problem of finding the pressure at a point of the sphere due to an incident wave is a classical one in diffraction theory, and for the case of a point at an *infinite* distance from the sphere (plane wave) calculations have been made[41] from which the dotted curve shown in Fig. 53 for a baffle three feet in diameter can be drawn. According to reciprocity this curve also represents the sound pressure at a large distance due to a piston vibrating at the pole of a spherical baffle. If the baffle were of infinite diameter (perfect baffle) the pressure would be doubled at all frequencies; hence the effect of the finite spherical baffle is to halve the pressure at low frequencies.

When the point P is at a *finite* distance from the sphere we have to deal with the diffraction of a *spherical* wave by the sphere instead of a plane wave. The mathematical theory of this case is considerably more complicated than that of the plane wave case and has been considered by Lamb.[42] Some calculations have been made by G. W

[41] Stuart Ballantine, *Phys. Rev.*, vol. 32, p. 988, (1928).
[42] Lamb, "Hydrodynamics," p. 486, 5th Ed., Cambridge, (1924).

Stewart in connection with the theory of diffraction by the head in binaural hearing. I have recently reëxamined the problem with the object of expressing the results in terms of Bessel functions whose orders are one half an odd integer. The final formula for the increase of pressure at the pole is

$$\frac{p}{p_0}=\frac{r-a}{\sqrt{ra}}\sum_{n=0}^{\infty}\frac{(2n+1)\left[(-1)^n J_{-n-1/2}(kr)-iJ_{n+1/2}(kr)\right]}{(-1)^n\left[(n+1)J_{-n-1/2}+kaJ_{n+1/2}\right]-i\left[(n+1)J_{n+1/2}-kaJ_{n-1/2}\right]} \quad (4)$$

where a is the radius of the sphere and r the distance between the source (point P) and the center of the sphere. The argument of the Bessel functions in the denominator is ka, where $k=\omega/c$. Computations for this spherical case are rather laborious on account of the slow convergence of (4) and the necessity for summing by special methods. I have carried them through for one case in order to exhibit the effect under discussion. This case is that in which the distance between point P and the spherical surface is equal to the radius of the sphere. The results are shown in Fig. 53 by the curve marked "distance = $1\frac{1}{2}$ feet." This represents the pressure which would be observed at this distance from the vibrating piston. It will be seen that as the microphone approaches the radiating surface the pressure at low frequencies increases. The experimental curves in Fig. 52 were taken with a loud speaker in an enclosed cubical baffle $3'\times3'\times3'$, and exhibit an effect of this sort.

When the back of the loud speaker is exposed, we have to deal with a double source and the effect is more pronounced. Kellogg[43] has given a qualitative explanation for this case.

The conclusion is that to get the proper effect of the cabinet the microphone should not be too close. The minimum distance will naturally depend upon the size of the cabinet. For cabinets of ordinary size, and for work of ordinary engineering accuracy, it is found experimentally that the microphone may approach within two feet of the loud speaker.

Measurements outdoors are usually embarrassed by inclement weather and wind, the number of clear, windless, good working days being surprisingly small. A gusty wind causes the deflections of the sound-pressure meter to become unsteady and it is impossible to judge by eye when a bona fide indication is being obtained. This unsteadiness is due presumably to a combination of effects such as variation of load on the loud speaker, variations in acoustical transmission, modulation

[43] E. W. Kellogg, *Jour. Acous. Soc. Amer.*, vol. 2, p. 157, (1930).

of loud speaker and microphone by gross displacements, and noise due to burbling around the microphone and variable pressure on its diaphragm.

In searching for some method of alleviating these effects it occurred to me several years ago that it might be possible to discriminate between the wind and the sound on the basis of the considerable differences in air velocities. The air-particle velocity involved in quite loud sounds is only of the order of a centimeter per second while in a ten-mile per hour gust it amounts to nearly 500 cm/sec, a ratio of 500:1. It is known from aerodynamical studies that any object, such as a cylinder, offers a resistance to airflow which is nonlinear with velocity.

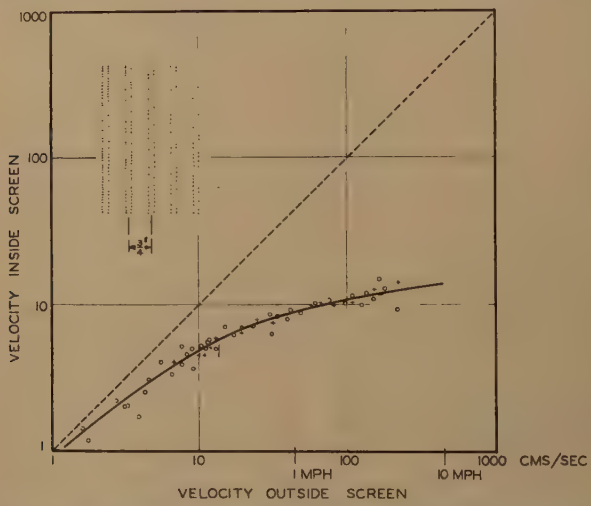


Fig. 54—Experimental curves showing shielding action of cubical wind screen at various air velocities.

At low velocities (Stokes régime) the resistance is chiefly conditioned by viscosity and is proportional to the velocity, and to a linear dimension. For a domain of still higher velocities the density of the fluid plays an important part since some of the force is due to momentum carried away from the surface by the fluid in the form of eddies and the resistance tends to vary as the square of the velocity. The velocity at which eddies begin to form, although not well defined, depends upon Reynold's number. On the basis of some published data from wind-tunnel tests on cylinders it was computed that a screen made up of threads, loosely woven, ought to exhibit a screening action which automatically increased with the velocity within the above range of velocities. Cheesecloth was considered to have approximately the desired

structure and an experimental model wind screen was built employing five double layers of cheesecloth spaced three quarters of an inch apart. This was cubical in shape and about four feet on each side. To determine the screening action a hot-wire anemometer was mounted in the middle of the enclosure for the purpose of measuring the velocity within the enclosure. The idea here is that as the velocity increases the walls become more and more impervious to penetration by the air stream with the result that this tends to flow around the box rather

Fig. 55—View of wind screen installation for outdoor electro-acoustical measurements.

than through it. The results of experiments on the model are shown in Fig. 54, where the abscissas represent the external velocities of the air relative to the screen and the ordinates represent the corresponding velocities within the screen. The attenuation of sound in passing through the screen was immeasurably small, certainly less than one decibel. It will be seen that a significant screening action was obtained; this automatically increased with the velocity in accordance with the theoretical expectations.

Following the successful tests of the model a full scale enclosure was built of sufficient height to permit a twenty-four-foot elevation of

the receiver and microphone. The wall structure was the same as that used in the model. A photographic view of this wind screen is shown in Fig. 55. Within this enclosure measurements can be carried out on the windiest days with complete freedom from disturbances.

Some reduction in wind disturbance can, of course, be obtained by the much simpler expedient of screening only the microphone, using the same type of screen. This is, however, not nearly so effective as the large enclosure, for obvious reasons.

Another method which I have employed to reduce the effect of adverse wind conditions in outdoor measurements is made practicable by the automatic recorder. The procedure merely consists in repeating the recording several times on one sheet. Unless the wind is continuous the possibility of securing a faithful indication at each frequency during at least one of the runs is sufficient to indicate the true characteristic, or at least to suggest its form. Usually three records are sufficient for moderately gusty winds. This method is, of course, not as satisfactory as the wind screen. The curves shown in Fig. 56 were taken by this method.

4. Outdoor Measurements with Back Wall

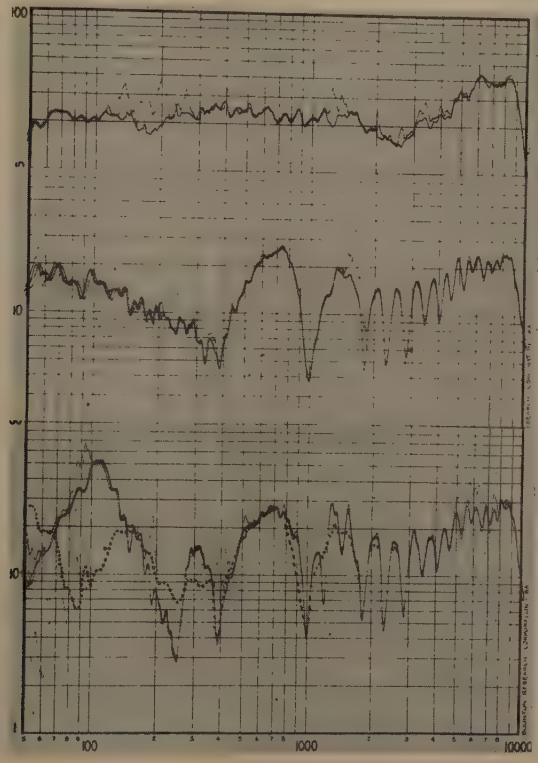
As ordinarily operated the loud speaker is surrounded by six or more reflecting surfaces. Of these, probably the most important are the floor and the wall immediately behind the loud speaker. When it is placed in a corner, two back walls have to be considered. Information of value can be obtained by taking sound-pressure curves under conditions which simulate the effect of these surfaces.

To simulate the effect of the floor it is merely necessary to place the receiver on the ground in its normal position. It is advisable to cover the ground with a rug so that room conditions are duplicated as closely as possible. The back wall we use measures about $15' \times 12.'$ The receiver is placed in front of this in the middle and, when the effect of the distance between it and the wall is not under investigation, about one foot from the wall. The construction should be as rigid as possible because the vibration of the back wall affects the low-frequency picture.

The effect of these surfaces on the sound-pressure characteristic of a receiver is shown in Fig. 56. The receiver employed two loud speakers, a cone for the reproduction of the low frequencies and a small horn for the higher frequencies.

The top record in Fig. 56 represents the response of the receiver under ideal conditions, that is, at a sufficient distance from all surfaces to avoid reflection.

The second curve was taken with the receiver on the ground and represents the effect of ground reflection. The minima due to ground reflection are plainly in evidence. The position of these minima and the shape of the curve depend upon the height and distance of the microphone. In this case the distance was eight feet and the height was forty-four inches, which represents the average height of the ears of a seated



ig. 56—Outdoor sound-pressure records of a receiver; (top curve) axial sound-pressure characteristic taken in free space; (middle curve) receiver on ground, microphone height, 44 inches, distance, 8 feet; (lower curve) receiver on ground with 12′×15′ back wall one foot behind receiver.

erson. The calculated frequencies of the minima agree very closely ith those recorded.

The bottom curve in Fig. 56 was made with the back wall in position. The receiver was one foot from the wall and the microphone distance and height were the same as for the middle record. The dotted urve in this record has been traced from a record made with the back the cabinet *closed*, to prevent the radiation of sound from the rear.

5. Indoor Measurements

Occasionally, due to inclement weather or for other reasons, one is obliged to work indoors. As is well known, the chief difficulty in acoustical measurements indoors is reflection from the walls of the enclosure. With regard to the fixed microphone there are two methods of reducing the errors due to this cause: (1) by acoustical treatment of the wall surfaces to reduce their reflectivity; and (2) by working with small distances between the microphone and loud speaker. The limitations of the latter expedient have been pointed out above. Our experiment and experience has shown that it is unwise to reduce the microphone separation to less than eighteen inches and our standard separation for indoor measurements is the same as that adopted for most testing outdoors, viz., two feet. This refers only to receivers of ordinary size and having single speakers.

Various absorbing materials and constructions are available for reducing the reflectivity of the walls. The relative efficiency of the various methods of treatment does not seem to have been systematically investigated. At the higher frequencies ordinary balsa wood or hair felt have reflectivities as low as ten or twenty per cent and are sufficiently effective. At the lower frequencies, the wavelength is so large compared with reasonable thicknesses of the material that such materials are no longer very effective, and special dissipative panel constructions are indicated. These may, of course, be associated with the hair felt, or equivalent material, for simultaneous absorption of the higher frequencies.

In any case the room should be as large as possible, as the ratio of the direct to the reflected sound varies as the size of the room. If in a room of a certain size we can work with a microphone separation of two feet with a given error due to reflection, a room of double the linear dimensions will permit doubling the microphone distance for the same error.

A comparison of sound-pressure measurements made in a small sound-testing room about $16' \times 16' \times 10'$ with those obtained outdoors under conditions approaching the ideal is furnished by Fig. 57. The curves represent the sound pressure on the axis of the loud speaker at various microphone distances. The loud speaker and mode of excitation were the same in each record, so they are directly comparable.

The effect of the room is somewhat in evidence even at the one-foot distance and increases rapidly as the microphone distance is increased. For ordinary engineering purposes the curves taken at one and two feet would be sufficiently useful since the serrations at the lower frequencies can be identified, for preliminary comparison purposes,

oom effects. It will be noticed that the effect of the enclosure diminshes at the higher frequencies on account of decreasing reflectivity and ncreasing directivity of the loud speaker and microphone.

The rotating microphone has been resorted to in order to diminish oom effects. This method has already been criticized.

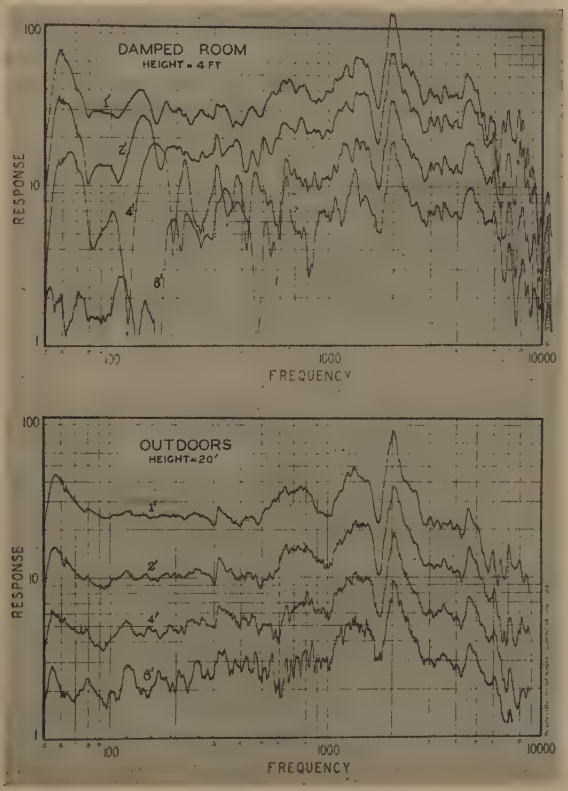


Fig. 57—Comparison of sound-pressure records of same loud speaker taken outdoors and in an indoor acoustical testing room.

Measurements in a Standard Living Room

Measurements made under favorable conditions outdoors and in pecially treated sound-testing rooms are valuable in development udies and for engineering purposes but do not by any means tell the hole story. What we want to know ultimately is how the loud speaker erforms in its natural acoustical habitat, which for our purposes may e taken to be the living room of the average home. This auditorium acoustically a part of the loud speaker and usually profoundly modies its performance.

Such rooms vary a good deal in size, shape, and acoustical charac teristics. Strictly speaking it is not possible to predict the performanc for a given room from measurements made in a room of different cha acteristics and dimensions. For routine testing purposes the best tha can be done is to employ an average living room having representativ dimensions, shape, and acoustical treatment. Our standard living roo is an attempt to achieve such a reasonable average and is based upo experience in testing in a variety of rooms. The reverberation an acoustical absorption have been carefully adjusted by means of ab sorbing panels, curtains, and a rug covering the floor.

The first studies in living rooms were made some time ago by th ordinary point-by-point method. On account of the relatively high re flections the sound pressure at any point fluctuates violently with th frequency, and measurements by this method require considerable tim and patience for their delineation.

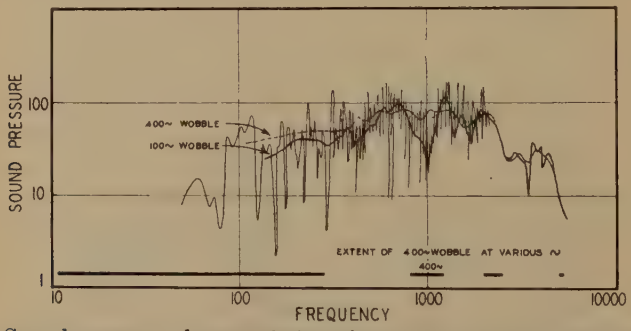


Fig. 58—Sound-pressure characteristics of a receiver in a reverberant roo illustrating effect of frequency wobbling in smoothing out fluctuations.

The next improvement in technique consisted in imparting a sma cyclic variation to the frequency and letting the output meter averag out the response.[44] Such "wobble" curves were found to represent ver closely the average sound-pressure variation at the higher frequencie (say above 500 cycles). By adjusting the extent of the frequency wob ble any desired amount of smoothing could be obtained. The wobble curves are not accurate at the lower frequencies, hence this part the curve is plotted by the ordinary point-by-point method. Fortu nately the fluctuations at low frequencies are not so rapid as at high frequencies so this can be done conveniently. The standard procedu then was to plot the pressure curves point by point up to 300–50 cycles, then to start the wobbler and continue the curve in that wa An example of the application of this method is shown in Fig. 58, take

[44] This method was described several years later and has also been employe by E. Meyer and P. Just, *Zeit. für Tech. Phys.*, vol. 11, p. 253, (1930).

n 1927. Two wobble amplitudes are shown. Naturally the larger mount of wobble produces the smoother curve. The 100-cycle wobbler urve will be seen to approximate closely the trend of the real charac- eristic.

The manner in which the wobbler method smooths out the serra- ions in the sound-pressure characteristic can also be understood from he steady-state point of view. Carson has shown[45] that if a small inusoidal variation is imparted to the capacity associated with an scillator the frequency undergoes a variation which is expressed by n equation of the following type:

$$I = A \sin\left(\omega t + \frac{\Delta f_w}{f_a} \sin at\right), \tag{5}$$

here Δf_w is the amplitude of the frequency variation, f_w is the mean requency, f_a is the frequency of capacity variation, and $a = 2\pi f_a$. He lso showed that this variable frequency current could be expressed in Fourier series as follows:

$$\begin{aligned} = {} & J_0(m) \sin at + J_2(m)[\sin(\omega + 2a)t + \sin(\omega - 2a)t] + \cdots \\ & + J_1(m)[\sin(\omega + a)t - \sin(\omega - a)t] \\ & + J_3(m)[\sin(\omega + 3a)t - \sin(\omega - 3a)t] + \cdots; \end{aligned} \tag{6}$$

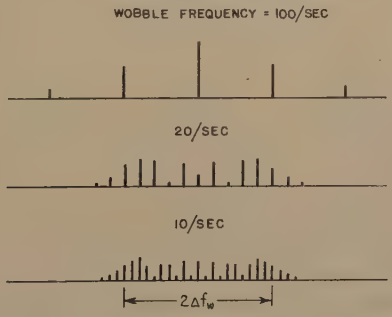


Fig. 59—Steady-state components of tone undergoing 100-cycle variation of frequency at rates of 10, 20, and 100 times per second.

here the argument m of the Bessel functions is $\Delta f_w/f_a$. The steady- ate current (6) is composed of a series of components having ampli- ıdes $J_n(m)$ and having frequencies disposed on either side of the mean equency f_w. The spectra of 100-cycle wobble ($\Delta f_w = 100$) at rates of), 20, and 100 per second are shown in Fig. 59. As the rate of the obble decreases the number of components increases while the width

[45] J. R. Carson, Proc. I.R.E., vol. 10, p. 57; February, (1922).

of the band remains practically constant. The distribution of energ among the components at the lower wobble rates is more or less un form. The presence of a large number of components acting simultane ously averages the response over the frequency region covered by th wobble. Since the number of components in the frequency interval in creases as the wobble rate decreases it is obviously advantageous t use as slow a rate of wobble as the ballistic properties of the indicatin device will permit. This conclusion from steady-state reasoning is con sistent with the fact that time is required for the energy to build u and die away in the room and a slow rate of frequency change favor this.

The required extent of the wobble at various frequencies depends among other things, upon the dimensions of the room. The eigen-fre quencies of the room are expressed by the second equation in Part I page 583. Considering a one-dimensional case, where a denotes th length, the resonances will occur at

$$f = cm/2a$$

where c is the velocity of sound and m is to be assigned integral value of 1, 2, 3, · · · . The resonances are integral multiples of the funda mental and are spaced in frequency at intervals of $c/2a$. If it be desire to average over a constant number of resonances at all frequencies th extent of the wobble should be constant at all frequencies and var inversely as the size of the room. Due to this requirement the metho becomes unsatisfactory at the low frequencies. This type of variatio of the extent of the wobble with frequency is shown in Fig. 58 at th lower part of the figure.

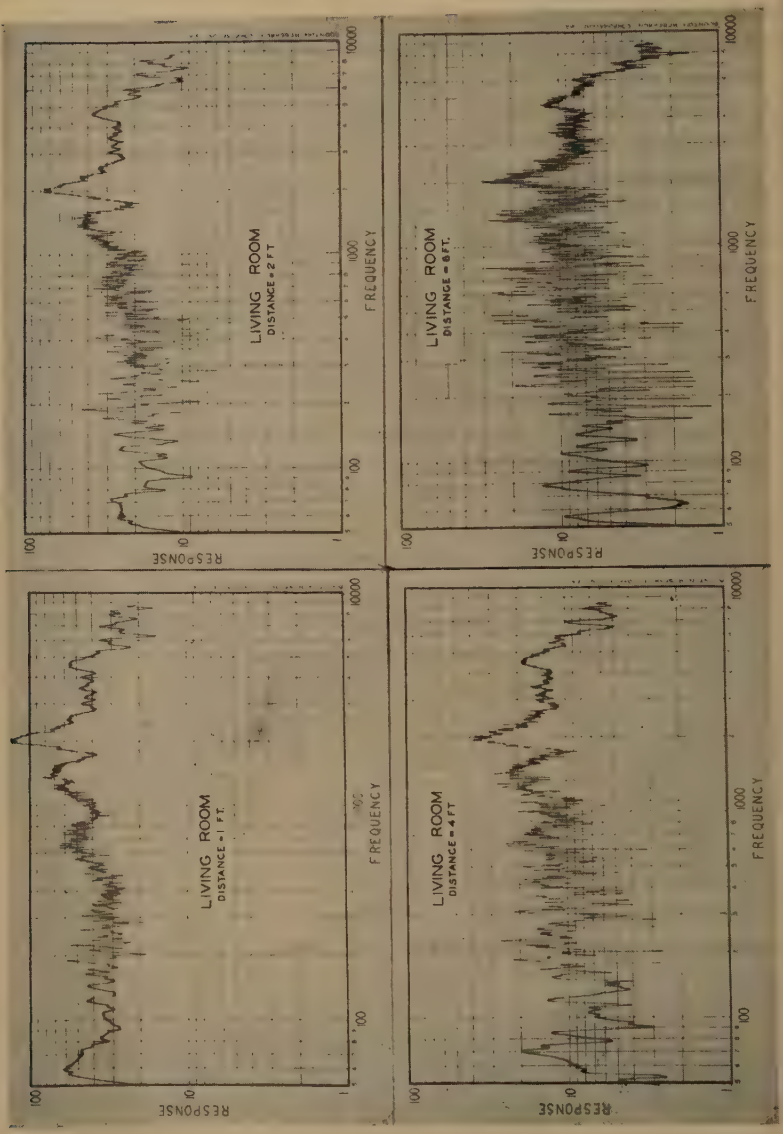
With the development of the automatic recorder the study of th performance of loud speakers in reverberant rooms was greatly simpli fied and a great deal of progress in this field has been made in the pas few years. Ordinarily by this means a record may be obtained in abou ten minutes, whereas by the older point-by-point method at least hal a day was required.

The actual sound pressure existing at any point of the room is th sum of the pressures due to an infinite number of component waves ar riving from various directions. Obviously to measure correctly th sound pressure in such a wave field it is necessary to use a microphon which responds uniformly to waves arriving from any direction. Ordi nary microphones, whose dimensions exceed a small fraction of an inch are unsuitable on account of their directivity. It is our practice there fore for such measurements to use a small piezo-electric microphone $1/4'' \times 1/4''$, which is nondirective for all frequencies of interest.

Specimen sound-pressure records taken in our standard living room are shown in Fig. 60. The microphone height was forty-five inches, which is about the height of the ears of the average person sitting in a chair. The microphone distances were one, two, four, and eight feet. The loud speaker in this test was the same one whose outdoor and sound-room characteristics are shown in Fig. 57 so that the characteristics obtained under these three conditions may be directly compared. The rapidly increasing serration of the curves as the microphone distance is increased is observable in Fig. 60. This is due, of course, to the increase of the reverberant sound in relation to the direct sound as the distance increases. It may also be noticed that the fluctuation decreases with rising frequency. This is probably due to two factors: (1) increasing concentration of the sound from the loud speaker along the axis; and (2) decreasing reflectivity of the walls and increasing absorption in the room, both occurring with rising frequency.

On account of the large percentage frequency spacing of the low-frequency peaks and depressions, and the large amplitude of fluctuation, *it seems doubtful if satisfactory reproduction of low frequencies in a small room will ever be possible.* The situation is made worse by the fact that at low frequencies the subjective loudness of sounds as perceived by the ear changes more rapidly with a change of sound pressure than at higher frequencies, so that the effect of these fluctuations in sound pressure are still further exaggerated by the ear. It is to be noticed that it is in this region that the sound-pressure characteristic of the loud speaker is most affected by the room. For these reasons one is not justified in spending too much effort in securing an inherently level response at low frequencies as measured outdoors; in fact a level response may be definitely undesirable. Entirely too much emphasis has been placed in loud speaker design upon level response down to low frequencies. *When the loud speaker is taken into a room the response characteristic at low frequencies is entirely changed and bears no relationship to the inherent performance as measured outdoors in free space.* As a starting point in designing a loud speaker a reasonable effort may be made to secure uniform response down to fifty cycles, but the final adjustments should always be made under actual living-room conditions. To secure the very best results the loud speaker should be "tailored" acoustically to fit the room. The most convenient way to carry out this "tailoring" is by means of compensators in the electrical circuits, and examples of this method will be given later in Part III.

The truth of the above remarks is well brought out by the records shown in Fig. 61. The response of this loud speaker outdoors was level within three decibels down to fifty cycles, the characteristic being sub-


LIVING ROOM
DISTANCE = 2 FT.
LIVING ROOM
DISTANCE = 8 FT.
LIVING ROOM
DISTANCE = 1 FT.
LIVING ROOM
DISTANCE = 4 FT.
RESPONSE
FREQUENCY
100
0
1
10000
1000

tantially as shown in Fig. 56 below 1000 cycles. In spite of this good outdoor characteristic the low-frequency response in the living room s extremely poor and exhibits violent fluctuations.

The pronounced effect of the room upon the response of the loud peaker has an important bearing upon the problem of formulating tandards for the uniformity of frequency response of high fidelity re-eivers. It would seem rational to allow some relaxation of the require-nents for uniform frequency response in frequency regions where the oom becomes the predominating factor, since obviously the effect of mprovements in the loud speaker in these circumstances is small. The rder of the effect of the room in producing fluctuations of sound pres-ure in a typical case is as follows:

TABLE I

Frequency Region	Total Fluctuation	Weighted for Ear
50– 250	30 db	60 db
250– 500	20	24
500– 1000	12	12
1000– 2000	7	7
2000– 4000	2	2
4000–10,000	1	1

his represents the total fluctuation. One half of these numbers repre-ent approximately the fluctuation on each side of the curve for the oud speaker as measured outdoors. The effect of these fluctuations vill be altered by the relation between the subjective loudness and ound pressure for the ear at various frequencies. According to the lat-st data on this[46] the effect will be confined to frequencies below 500 ycles. At 100 cycles the variation in sound pressure required to pro-luce a given variation in loudness is about half as great (measured in ecibels) as at frequencies above 500. The last column in Table I in-ludes the effect of the ear. A thirty-decibel variation at 100 cycles is quivalent to a sixty-decibel variation above 500 cycles, and so forth.

Instead of specifying an allowable uniform fluctuation of ± 2.5 deci-els over the entire frequency range for a high fidelity receiver, this ould be weighted in accordance with the above data to allow for the ffect of the room at each frequency. As an arbitrary basis for this veighting we might specify a fluctuation in the loud speaker at low requencies equal to a certain percentage of the room effect, and super-ose this on the above basic tolerance. The following specification for a igh fidelity receiver, derived in this way, may be proposed:

[46] H. Fletcher and W. A. Munson, *Jour. Acous. Soc. Amer.*, vol. 5, p. 91, 1933).

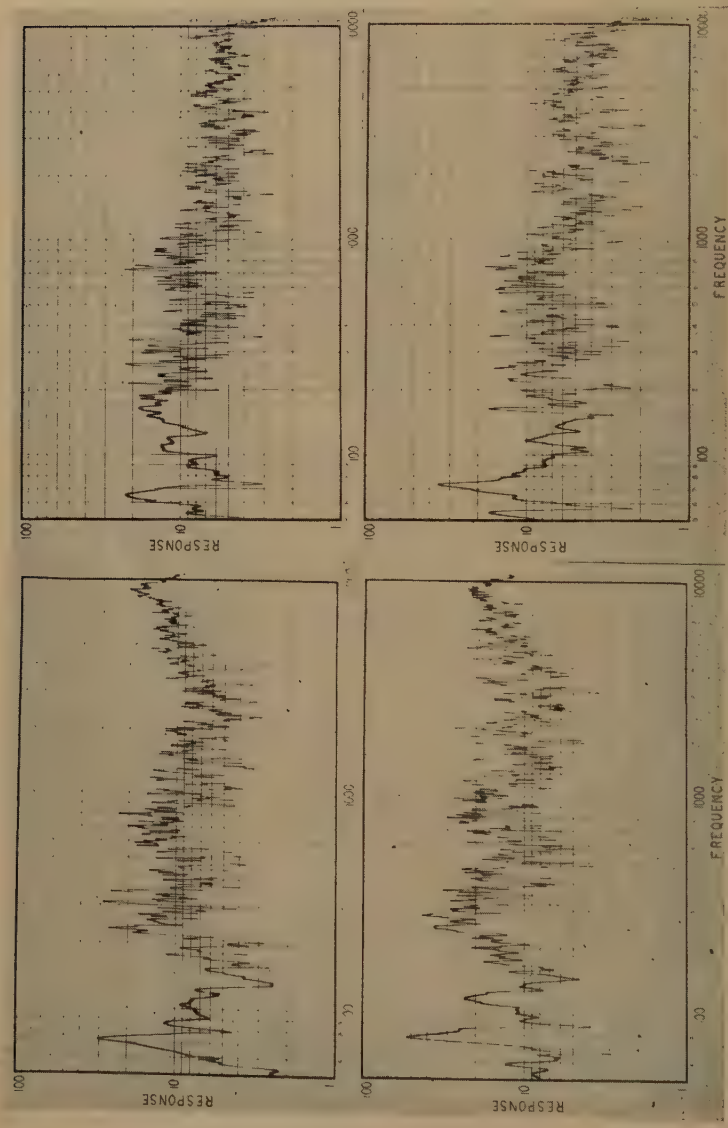


Fig. 61—Sound-pressure records taken in a standard living room showing effect of various microphone locations, microphone distance constant.

TABLE II

Proposed Specification for the Permissible Fluctuation in Response of a High Fidelity Receiver

Frequency	Fluctuation
50	±10 db
100	±7
500	±4
1000–8000	±2.5

These figures may be regarded as tentative, subject to the test of future experience, but illustrate the principle which it is felt should govern the formulation of tolerances.

The sound-pressure characteristics as measured at a point in a room varies, as one would expect, with the position of the loud speaker in the room, the position of the microphone in the room, and the size, shape, and furnishings of the room.

The effect of the position of the microphone in the room is shown in Fig. 61. In view of the variation between different locations our practice is to take records at certain chosen microphone locations and to average out the results. These locations are generally at −45°, −25°, 0°, +25°, +45° at 12 feet distance and at 0°, 8 feet distance, all angles being with respect to the plane of the loud speaker axis. After the average curves have been obtained we have sufficient data for the design of electrical compensators or other means of smoothing out the average response. This procedure has been followed out in the design of the high fidelity receivers to be described in Part III of this article and the results seem to be well supported by subjective judgments of performance.

The effect of the position of the loud speaker in the room is shown in the four records reproduced in Fig. 62. In all cases the microphone was located in the plane of the axis of the loud speaker. The two positions of the loud speaker were typical ones; in the upper records the receiver was located in a corner with the axis of the loud speaker at forty-five degrees to the two walls; in the lower records it was against a side wall, approximately midway between the corners, and about three inches from the wall. This loud speaker was the one recorded in Fig. 56 and had substantially uniform response as measured outdoors.

In the left-hand records the receiver cabinet was completely closed in order to eliminate acoustical radiation from the rear. In the right-hand records the back of the cabinet was open. The purpose of this experiment was to test an opinion I had held for many years, on theoretical grounds, namely that when a loud speaker is installed in a room it should be beneficial to eliminate the acoustical radiation from the rear. This idea was opposed to current practice in which the conventional receiver cabinet was thoroughly ventilated to allow free escape

of the sound from the rear, sides, and bottom. The experimental curve shown in Fig. 62 indicate, however, that no general statement can b made concerning the desirability of suppressing the radiation from th rear. Whether this is desirable or not depends upon the position of th loud speaker in the room, and also undoubtedly upon other factors no varied in this experiment. For example, in Fig. 62 the smoothest re sponse is obtained with the receiver against the wall with the back i place (lower left-hand curve). With the reciever in the corner, th

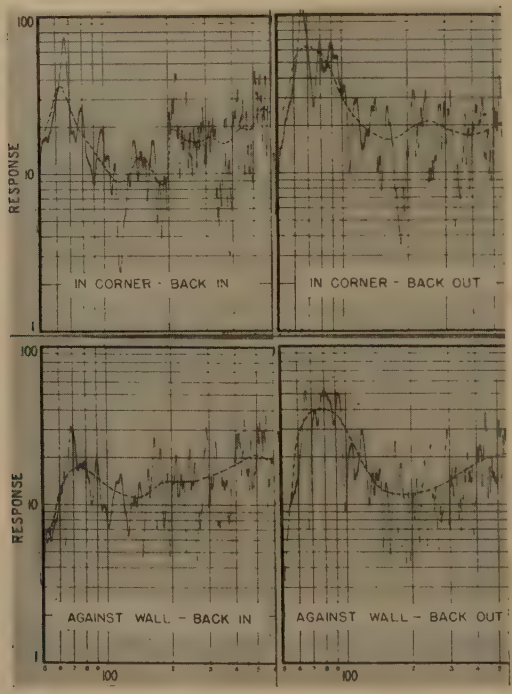


Fig. 62—Illustrating effect of location of receiver in living room.

average response (dotted line) is smoother when the back is out (upp right-hand record) than when it is in place. A smooth average respon is important because it is easier to equalize in the electrical circuit From this viewpoint the upper right-hand curve in Fig. 62 is somewh preferable to the upper left-hand curve. In this particular case wh the receiver is installed against the wall, the back is put in and t electrical room-equalizer is cut out; when it is installed in the corn the back is removed and the electrical equalizer is cut in. This is example of the application of what we described above as tailoring t receiver acoustically to fit the room.

The horn-like effect of the corner in building up the response near seventy cycles is plainly in evidence in these records, especially those with the back of the cabinet out. The peak in the neighborhood of seventy cycles is probably due to the conjunction of lower resonant frequencies of the room, the dimensions of which were $9.4 \times 4.7 \times 3.35$ meters. (The length is exactly twice the width.) The first-order eigen frequencies corresponding to the length, breadth, and height of the room are obtained by substituting in the second equation, Part I, page 583, and are

length—	17.5,	35,	52.5,	70,	88,	105,	122,	140	cycles
breadth—		35,		70,		105,		140	
height—			50,		100,				150.

The greatest effect is obtained at the first conjunction at thirty-five cycles, as shown by the oscillographic response of a microphone to shock excitation,[47] and the next highest rise occurs at seventy cycles. Due to these conjunctions this room is not a particularly good one. The room dimensions should be such that none of them is an integral multiple of another and such that the eigen-frequencies shall be separated as much as possible, especially in the region of 50 to 150 cycles.

The simplest method of eliminating acoustical radiations from the rear is to enclose the cabinet completely. The principal change in the acoustical impedance presented to the back of the loud speaker piston caused by this is an increase in the stiffness which can be allowed for in the design of the speaker. Resonances at higher frequencies may be discouraged by lining the cabinet with sound-absorbing material, although as an experimental fact I have never found that these give a great deal of trouble.[48]

There has been a great deal of discussion about the effect of "cabinet resonance" on the response characteristics of loud speakers. There is no doubt that this exists. We have seen how the pressure on the diaphragm of a condenser microphone is built up by a factor of three to one due to acoustical resonance in the cavity in front of the diaphragm; in the same way the radiation from the rear of the loud speaker is influenced by resonance in the cavity formed by the receiver cabinet when it is open in the rear. The trouble, however, is this: when the receiver is outdoors in the open we can properly speak of cabinet resonance since it is a perfectly definite thing; but when the receiver is

[47] When a loud speaker of conventional design is shock-excited in an ordinary room the microphone registers free oscillations corresponding to the resonances of the room and not of the loud speaker, as has been stated.

[48] Note added April, 1935: A method which has quite recently been adopted in a commercial receiver for eliminating radiation from the rear employs a so-called "acoustical labyrinth."

taken into a room the cabinet resonance is profoundly modified by th presence of the walls. In these circumstances the resonant frequencie are changed. The term "cabinet resonance" is no longer proper sinc the cabinet is a small part of the picture. For the same reason the us of Helmsholtz resonators mounted in the cabinet to absorb sound a the resonant frequencies of the cabinet, as has been proposed and ca ried out in one commercial receiver, is of doubtful value due to th wide variation in the resonant frequencies in different locations of th receiver with respect to adjacent wall structures. As a matter of fac I have never been able to detect experimentally any substantial benefi from such absorbing devices under practical conditions.

Finally the variation from room to room is illustrated in the se of records reproduced in Fig. 63. The loud speaker was the same in a cases and in each room was located against a side wall with the micro phone in the axial plane at a distance of eight feet. The sizes of th rooms varied from $10' \times 10' \times 8'$ to $32' \times 16' \times 11'$.

A question which arises in connection with the perception of soun in a reverberant room is this: Is there any definite relation between th sound pressure as measured *at a point* by the above methods and th pressure which is present at the external ear of a listener at that point A little consideration shows that in the general case the answer i "no." The pressure at the ear differs from the pressure in an inciden plane sound wave on account of diffraction around the head. The rati of the pressure at the ear to that in the undisturbed wave depends upo the frequency and the angle of incidence. In a reverberant room th sound at any point is due to an infinite number of waves of variou intensities arriving from various directions. The pressure at the ear wi be obtained by summing up, with due regard to the effects of diffrac tion, the effects of these component waves. Obviously the resultin pressure will differ from the pressure at that point as measured by nondirectional microphone.

As a means of obtaining a measurement of pressure approximatin the acoustical pressure present at the ear, the apparatus shown in Fig 64 was constructed in 1930. This is virtually a spherical artificial hea with condenser microphones for ears. The diameter of the spherica mounting is equal to the average distance between the ears. The con denser microphones are of special construction (vide reference 2) an the diaphragms are virtually part of the spherical surface.

Either microphone could be connected to the recorder, or using tw complete separate channels the outputs could be combined, as show in Fig. 65. It was expected that the use of two microphones would ten to smooth out the fluctuations at higher frequencies. As a matter

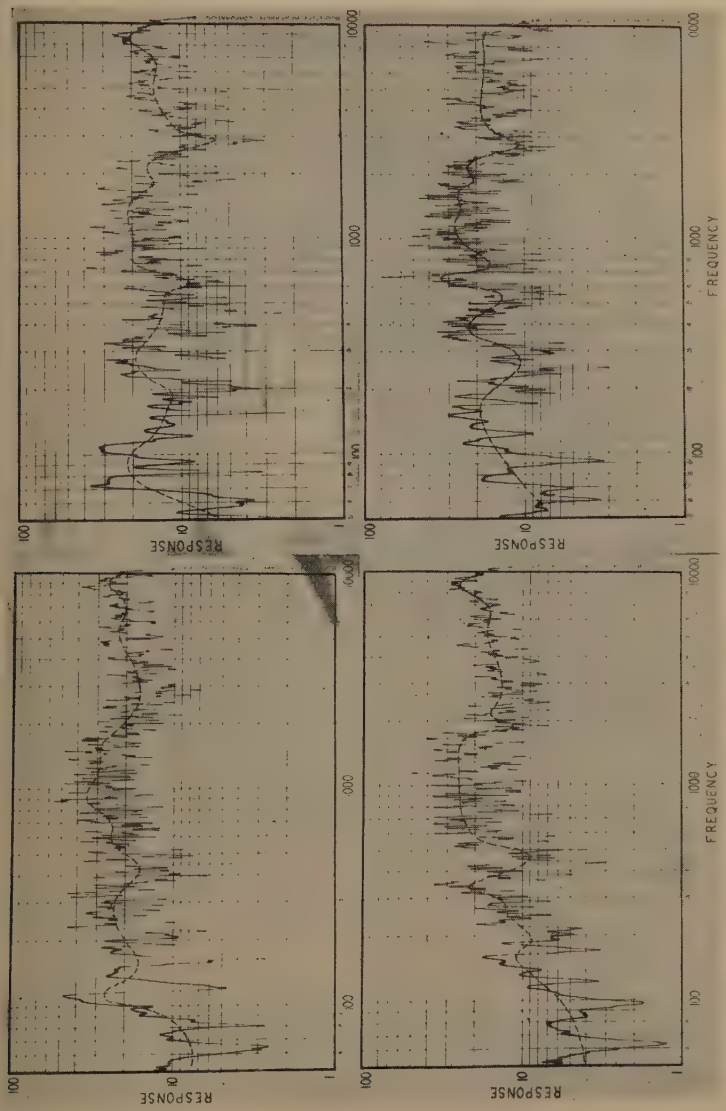


Fig. 63—Sound-pressure characteristic of same receiver in different rooms.

fact there is surprisingly little difference between the records madi with one microphone and records of the combined output of bott microphones. Typical records made under the two conditions are show in Fig. 66. There is some smoothing out in the lower record, but not as much as had been expected.

Fig. 64—Artificial head employing condenser microphones at ear locations.

It has long been known that a much smoother subjective respons to sounds originating in a reverberant room is obtained by listenin with both ears in the normal way than is obtained with one ear. On of the theories which has been advanced to explain this superiority c

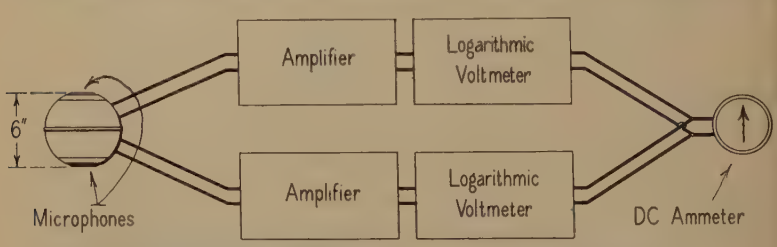


Fig. 65—Scheme of connections for tests with artificial head.

binaural over monaural pick-up is that the single ear finds itself at ce tain frequencies in a pressure null point whereas with two ears th probability of both ears being simultaneously in a pressure null poi is considerably smaller. The two ears tend to help one another; whe one is inactive some sound is still picked up by the other. This may b

expected to take place at the higher frequencies when the dimensions of the head are comparable to the wavelength of the sound. The curves in Fig. 66 would appear to show, however, that this smoothing effect is actually too small to account for the subjective observations.

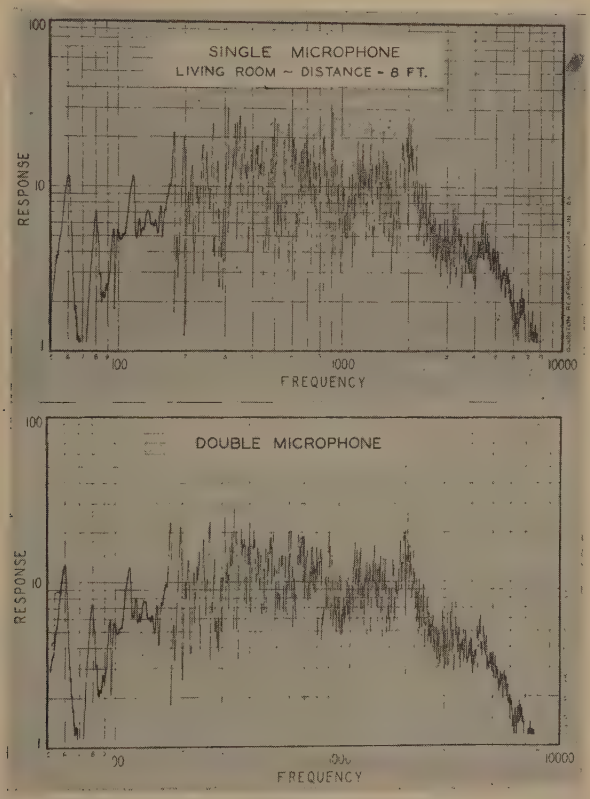


Fig. 66—Sound-pressure characteristics in reverberant room taken with artificial head, (upper curve) one microphone, (lower curve) both microphones.

7. *Summary*

The over-all fidelity of a broadcast receiver may be determined by introducing into an artificial antenna a standard modulated signal of variable modulation frequency and plotting the sound pressure against modulation frequency.

The sound pressure should be measured by a pressure-operated microphone, not by a velocity microphone. The microphone should preferably be fixed in position and not rotated or moved in any way. The most fundamental characteristic is obtained with the microphone on the axis of the loud speaker. The directivity of the loud speaker should

also be determined by making measurements with the microphone set at several angles to the axis.

The most favorable acoustical conditions for such measurements are found outdoors. For receivers of average size with a single loud speaker a standard microphone distance of two feet is recommended. For receivers with more than one speaker the microphone distance should be increased in proportion to the increase in the greatest overall dimension of the radiating surface. Both receiver and microphone should be sufficiently elevated above the earth to avoid the effects of reflection. A height of five to ten feet is satisfactory for a two-foot microphone distance, and proportionally greater heights for greater microphone distances. Measurements made outdoors may be regarded as supplying fundamental (but by no means final) information concerning the frequency characteristic of the receiver or loud speaker.

When it is not convenient to make measurements outdoors a specially damped testing room may be used. This should be acoustically treated to reduce reflections and should be as large as possible. A standard microphone distance of two feet is recommended for ordinary receivers with a single loud speaker. Larger distances, as required by multiple speakers, are not in general satisfactory for rooms of average dimensions because of the effects of reflection.

The ultimate performance of the loud speaker, or receiver, should be determined in the room in which it is actually to be used. This is generally inconvenient but measurements in a standard room, having the dimensions and acoustical characteristics of the average living room, will serve as a substitute. The sound-pressure characteristic depends upon the position of the loud speaker and the microphone in the room. In view of this it is recommended that two standard loud speaker positions be adopted (1) in a corner, and (2) flat against the middle of a side wall—and that for each of these positions a curve be taken with the microphone at azimuths of $-45°$, $-25°$, $0°$, $+25°$, $+45°$ at a distance of twelve feet and height of forty-five inches. Average curves should be drawn for each position, smoothing out the serrations due to the standing wave pattern. Then an average of the average curves should be drawn. Final adjustments should then be made to smooth out this average curve, probably by electrical compensation. A nondirectional pressure microphone should be employed for living-room measurements or in any circumstances where the sound field is comprised of several components arriving from different directions.

(The discussion of the *Receiving System*, including a description of experimental model high fidelity receivers, will be concluded in Part III of this paper which, it is expected, will be published in a subsequent issue of the PROCEEDINGS.)

Proceedings of the Institute of Radio Engineers
Volume 23, Number 6 *June, 1935*

A HIGH-FREQUENCY SWEEP CIRCUIT*

By
T. T. Goldsmith, Jr., and L. A. Richards
(Department of Physics, Cornell University, Ithaca, N. Y.)

Summary—*A linear high-frequency sweep circuit for the cathode ray oscillograph is described. It employs a linearly charged condenser periodically discharged by a hard tube, the grid of which is biased past cut-off except for short periods when it is driven positive by an auxiliary oscillator. The frequency of this oscillator is made commensurable with that of the unknown wave form to be investigated. The circuit is particularly adaptable for high frequencies, photographs of alternating voltages of frequencies up to twelve megacycles being shown.*

THE usual method for obtaining a cathode ray tube linear time axis is to make use of the uniform rise in voltage resulting when a condenser is charged by a constant current and then periodically discharged by a glow discharge in a gas-filled tube.[1,2,3] In such tubes the discharge frequency and hence the sweep frequency is definitely limited by the gas deionization time. During the spring of 1933 while trying to obtain high sweep frequencies it was decided to avoid such a limitation by using a hard tube to discharge the sweep circuit condenser. This may be done if the high vacuum tube used to discharge the condenser is biased past cut-off except for short intervals when the grid is driven positive by an auxiliary oscillator.

When this investigation of such a sweep circuit was nearing completion, it was found that a similar scheme was being used by Zworykin.[4] The high-frequency advantage of the circuit however is not necessary in the television application, and the present paper shows that the hard tube sweep circuit, used in connection with high vacuum cathode ray tubes, considerably extends the frequency range over which stabilized wave patterns may be obtained.

A signal generator applies the waves to be investigated to the Y plates of the cathode ray tube. The X plates are connected directly to the sweep circuit condenser which is charged by current from the

* Decimal classification: R388. Original manuscript received by the Institute, September 5, 1934; revised manuscript received by the Institute, February 5, 1935.

[1] Bedell and Reich, "The oscilloscope: a stabilized cathode ray oscillograph with linear time-axis," *Jour. A.I.E.E.*, vol. 46, pp. 563–567; June, (1927).

[2] Haller, "A linear timing axis for cathode ray oscillographs," *Rev. Sci. Instr.*, vol. 4, pp. 385–386; July, (1933).

[3] Meier and Richards, "Power supply and linear time axis for cathode ray oscillographs," *Electronics*, pp. 110–112, April, (1934).

[4] Zworykin, "Experimental television system and kinescope," Proc. I.R E., vol., 21, pp. 1655–1673; December, (1933).

charging tubes during the linear portion of the sweep, and then dis-charged by the plate current of a 59 tube. When connected as a class B triode this tube requires only a low negative bias for plate current cut-off and can pass large currents when the grid is driven positive, thus allowing rapid discharge of the sweep circuit condenser. The filament of this tube is operated for convenience from a storage battery, and the tube, its battery, and its entire feed circuit are placed in a shielding copper box.

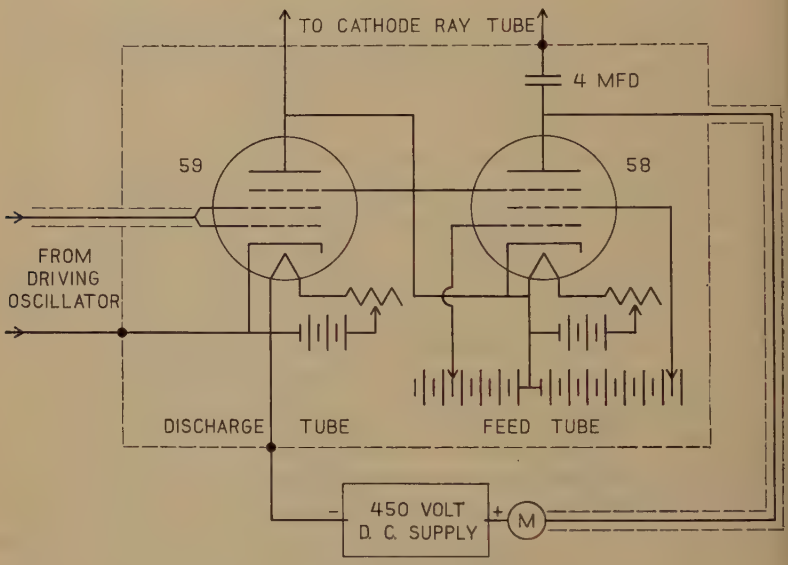


Fig. 1—Discharge tube and feed circuit.

The constant current for charging the sweep circuit condenser is supplied by four 58 tubes connected in parallel. The diagram of connections is given in Fig. 1, only one of the 58 tubes being shown.

For high frequencies it is desirable that the sweep circuit condenser have a low capacitance. The distributed capacitance of the circuit connected with the plate and cathode of the 59 tube is more than adequate for this purpose, and should be kept low by keeping the battery system of the charging tubes well spaced from the shielding case. The effective value of this distributed capacitance for our circuit was found to be 274 micromicrofarads.

A Hartley oscillator drives the sweep circuit. In order to obtain sufficient power over a wide range of frequencies, a type 250 tube is used with 45 volts grid bias and a plate supply of 450 volts with a variable plate resistor to prevent overheating of the tube. The center

of the tank circuit, consisting of grid and plate coils in series, with the tuning condenser across them both, is biased several volts negative to the cathode of the 59 tube. In this way, the output signal, tapped from about the middle of the grid coil and going directly to the grid of the discharge tube, has the proper bias for that tube. By adjusting this bias, only the very peaks of the oscillations are used to swing the discharge tube grid positive, making the tube conducting, and the entire remainder of the cycle is free for the linear portion of the sweep. Of course it is necessary that the grid stay positive long enough for a complete discharge of the plate capacitance.

Careful shielding of the driving oscillator from the output of the sweep circuit is necessary, no shielding being used on the lead from the sweep circuit to the cathode ray tube, as such shielding would very materially increase the distributed capacitance in the circuit.

We obtained the unknown wave form for the *Y* plates from a feedback oscillator using a tuned grid circuit.

In order to produce steady patterns on the screen of the cathode ray tube, some means of stabilization[1] has to be employed. By having both oscillators at ground potential it is a simple matter to produce enough coupling between the two circuits to cause them to keep in step when tuned to nearly the same or multiples of the same frequency. For precise work, it is of course best to see that the driving oscillator is completely shielded, so it will have no effect on the circuit under observation. A very small amount of the unknown voltage can be led into the case with the driving oscillator to pull it into step. Stray coupling proved sufficient in taking the pictures shown, working best when a small ratio of unknown frequency to driving frequency was used.

The ideal linear sweep circuit demands a return sweep which takes place so rapidly that the trace is invisible, but actually the discharge of the capacitance takes a finite time. However, the return time may be minimized by adjustment of the discharge tube grid bias as described above. An inspection of Fig. 2 will show the characteristic of the return sweep. As the cathode ray tube happened to be arranged, the linear portion of the sweep actually takes place from right to left, and the return sweep begins at the left and goes to the right. In Fig. 2 the return sweep takes a little more than one cycle, after which the grid of the discharge tube remains positive for the next two cycles, holding the spot at the zero position all of this time. With more careful adjustment of the bias than was here used, this extra holding of the spot in the zero position could be eliminated, as may be seen in the other pictures.

Another method of minimizing the interference of the return sweep on the waves to be studied might be the use of some scheme to turn off the cathode ray beam during this part of the cycle.

The actual linearity of the sweep circuit was checked only by the photographs of sine waves such as those here given, though at lower frequencies it was checked against a standard sweep circuit.

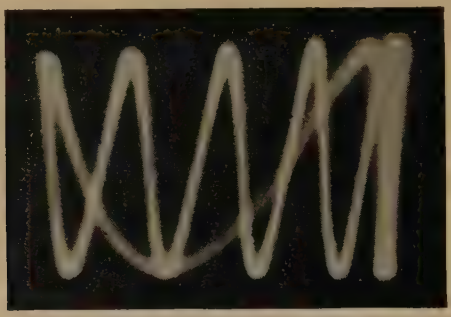


Fig. 2—4.2 megacycles per second.

A standard wave meter indicated directly the frequency of the driving oscillator, the frequency of the unknown waves being derived from an inspection of the recorded pattern. The photographs were made with an f4.5 lens on portrait panchromatic film with about a one-

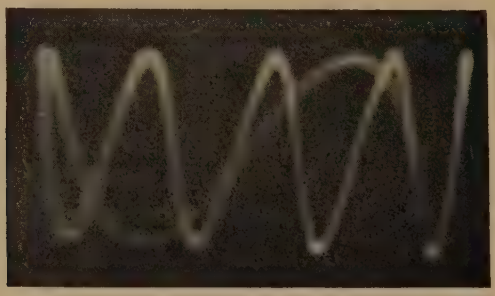


Fig. 3—6.0 megacycles per second.

second exposure. The pictures here shown are enlargements from the original negatives. The actual lengths of Figs. 3 and 4 were a little over one inch, with respective feed currents of 31.5 and 61.0 milliamperes.

With smaller feed currents and added capacitance the circuit may well be employed for waves of lower frequencies than those shown here. Higher frequencies might be attained with this circuit by using higher feed and discharge currents.

It can be noticed in all of these pictures that the peaks of the waves are tilted slightly in a clockwise direction about their centers. The difficulty may be the intercoupling within the cathode ray tube be-

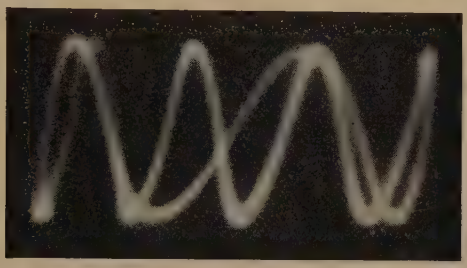


Fig. 4—12.0 megacycles per second.

tween the leads to the deflecting plates, since a type RCA-906 was used. Such coupling is to be expected at high frequencies and can be avoided only by use of a cathode ray tube with deflecting plate leads brought out through individual seals around the tube.

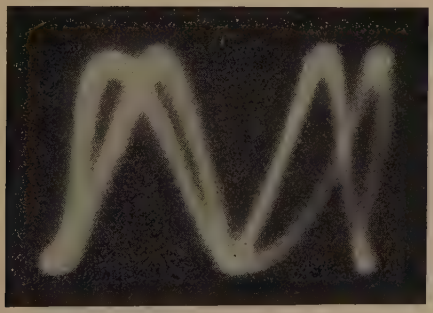


Fig. 5—12.6 megacycles per second.

ACKNOWLEDGMENT

While associated with the authors on sweep circuit work, Franklin Offner made the initial suggestion of using a high vacuum tube for discharging the sweep circuit condenser.

Proceedings of the Institute of Radio Engineers
Volume 23, Number 6 *June, 1935*

REPORT ON IONIZATION CHANGES DURING A SOLAR ECLIPSE*

By

E. V. Appleton
(King's College, London, England)

AND

S. Chapman
(Imperial College of Science and Technology, London, England)

Summary—*The effect of a solar eclipse upon air layers ionized by different solar agencies is described, and the observations of the actual eclipse changes in ionized layers are considered. The conclusion is reached that the normal ionizing agency for regions E and F_1 has a speed closely agreeing with that of light; hence it is natural to identify this agency with ultra-violet light (though observations of the kind here considered cannot rule out the possibility that the agency, for one or more of these layers, consists of very high speed corpuscles). Similarly there is fairly definite evidence that ultra-violet light contributes at least a part of the normal region F_2 ionization, and a suggestion that corpuscles may also contribute. In future eclipses it is very desirable that attention should be specially concentrated on this region F_2.*

THE ionization of the upper atmosphere has a pronounced daily variation, which indicates that the sun is a main factor in producing the ions. Since the ionization is greater by day than by night, the solar ionizing agent must travel to the earth along an approximately radial path; this is in strong contrast with the solar action that produces auroras and the abnormal ionization observed in high latitudes during periods of strong magnetic disturbance. It is commonly supposed that the latter group of phenomena are due to electric particles from the sun, which are much deflected in the earth's magnetic field, so that they impinge mainly in high latitudes, and over the dark as well as over the day hemisphere. The normal ionization, on the other hand, is to be attributed either to ultra-violet light, or to neutral corpuscles projected from the sun, since neither of these agents would be deflected by the earth's magnetic field, and so would impinge only on the day hemisphere.

It is possible to distinguish between these alternative sources of normal ionization by means of radio observations during a solar eclipse.[1] The test depends essentially on the difference between the

* Decimal classification: R113.61×R113.55. Original manuscript received by the Institute, December 13, 1934.

[1] Attention was drawn to this possibility at a geophysical discussion at the Royal Astronomical Society on January 29, 1932, (*cf. The Observatory*, March, 1932), and in a letter to *Nature*, May 21, (1932).

speeds with which the two kinds of radiation travel towards the earth, and the ratio of these speeds to the moon's orbital motion. The shadow region extending from the moon on the side more distant from the sun is not radial from the sun; it lags behind this radial direction, by an angle whose circular measure is the ratio of the moon's speed to the speed of the radiation. This angle is negligible in the case of ultra-violet radiation, but is approximately one degree for neutral corpuscles having a speed of 1000 miles a second. The speed of the supposed corpuscles is unknown, but E. A. Milne[2] has shown that the sun is likely to be constantly emitting particles at about the speed named, and a similar speed has been inferred, for the *charged* particles supposed responsible for magnetic disturbances, from the time lag between these events and the central passage of sun spots apparently associated with them.

A consideration[3] of the geometrical and time relations in the passage across the earth of the regions shaded by the moon from the sun's light and from the slower moving corpuscles shows that the corresponding eclipses will occur at different places and different times. They may, therefore, be distinguished by separate names; i.e., as the "light" or "optical" eclipse (the same for ultra-violet light as for the visible light by which the eclipse is ordinarily observed) and the "corpuscular" eclipse. It appears that, for the corpuscular speed mentioned, the corpuscular eclipse will precede the optical eclipse by about two hours in time and will occur much to the east of the track of optical totality, by a distance exceeding 1000 miles; the exact time and location must of course be calculated separately for each eclipse (assuming some definite speed for the particles). The suggested difference between the two types of eclipse is so great that radio measurements of the upper air ionization, made at suitably situated stations, should be able clearly to distinguish between them. If ultra-violet radiation is the main ionizing agent in a particular layer of the upper atmosphere, the electron density at a point in this layer above the track of optical totality should attain its minimum a few minutes after the central instant of optical totality; but if corpuscular ionization is the main cause, the minimum electron density should occur earlier, and to the east of the total shadow track.

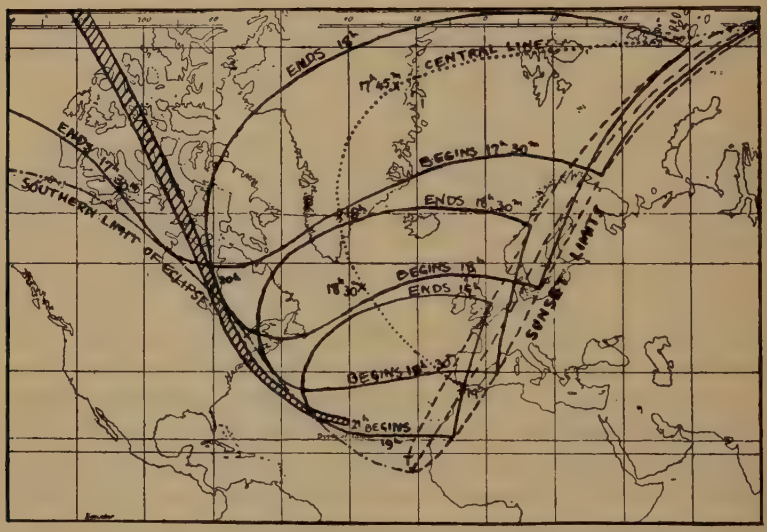
Observations were, therefore, arranged by many radio research institutions to test these alternative possibilities at the eclipses of August 31, 1932, and August 21, 1933.

[2] Monthly Notices *R.A.S.*, vol. 86, pp. 459–578, (1926).
[3] Monthly Notices *R.A.S.*, vol. 92, pp. 413–422, (1932).

Record of Results Obtained.

From what has been said above it is clearly advantageous to deal with the experimental results according to whether they are concerned with the optical eclipse or with the corpuscular eclipse.

Before proceeding to their summary and discussion, however, a word or two of explanation is necessary. It was discovered by radio methods in 1927 that the ionosphere may be divided into two main regions which were called region E (lower) and region F (upper). (The lower region is the well-known Kennelly-Heaviside layer.) The maxi-



Published with the permission of the Royal Astronomical Society

Fig. 1—Eclipse of August 31, 1932. Track of optical totality (shaded) and of corpuscular eclipse.

mum ionization in each region undergoes a diurnal variation, being greater by day than by night. Later, evidence was put forward showing that, during the daytime only, there is regularly formed a kind of lower shelf on region F, while occasionally there is an intermediate maximum of ionization between region E and region F. (Intermediate region.) For purposes of distinction we have, therefore, at increasing heights in the atmosphere:

(1) Region E (regularly occurring),
(2) Intermediate region (occasionally occuring in the daytime),
(3) Region F_1 (shelf-region, occurring only in the daytime),
(4) Region F_2 (main F region, regularly occurring).

During the eclipse of 1927 in England, ionospheric observations were made on medium and long waves reflected from region E only, and such observations were confined to measurements of equivalent height and intensity of downcoming waves.

In the case of the eclipses of 1932 and 1933 it was possible to make observations of a more direct physical character using the critical frequency method of measuring maximum ionization content. This method, first described[4] in 1931, had by 1932 been used for the study of the diurnal and seasonal variations of regions E and F and the details of its application had been sufficiently worked out to suggest that it would prove useful in the case of the special eclipse observations.

(A) Eclipse of August 31, 1932, in America

Optical Eclipse: Region E.

(1) *Observations made by J. T. Henderson at Vankleek Hill, Ontario, Canada.* (*Canadian Journal of Research*, vol. 8, January, (1933).)

Measurements of the maximum ionization content were made over the period 1400 to 2400 G.M.T. on August 31 and compared with the average results obtained during a similar period on a number of control days. The results obtained were quite decisive in indicating that the ionization in the path of the shadow decreased by at least fifty-eight per cent during optical totality.

(2) *Observations made by Kirby, Berkner, Gilliland, and Norton at Washington D.C., and at Sydney, Nova Scotia.* (*Bureau of Standards Journal of Research*, December, (1933).)

Measurements of the ionization content by Appleton's critical frequency method were made. It was found that at both sites the ionization decreased to about thirty per cent of its normal value, the variation taking place approximately in phase with the optical eclipse.

(3) *Observations at Deal, N. J. by J. P. Schafer and W. M. Goodall.* (*Science*, November 11, (1932).)

Equivalent height measurements on the frequencies of 2.4, 3.5, and 4.8 megacycles were made from which the observers deduce that the ionization in region E reached a minimum value at 3:45 p.m. (E.S.T.) (The optical eclipse was at its maximum at Deal at 3:34 p.m.)

[4] E. V. Appleton, *Nature*, February 7, (1931); see also Appleton and Naismith, *Proc. Roy. Soc.*, A, vol. 137, p. 36, (1932), for further details.

(4) *Field strength observations at British Post Office stations during the eclipse period.*

Observations were made on signals from Laurenceville (13.39 megacycles during 1700 to 2300 G.M.T. from August 29 to September 2 inclusive and on signals from Rocky Point (60 kilocycles) from August 20 to September 1 inclusive. Nothing abnormal was observed at either Dollis Hill or Baldock but Cupar in Scotland reported a marked decrease of field strength on August 31 between the times 2015 and 2018 G.M.T. (60 kilocycles). This is indicative of an ultra-violet light effect on region E because the effect was similar to a return to night-time conditions.

Optical Eclipse. Region F_1

(1) *Observations made by Kirby, Berkner, Gilliland, and Norton at Washington, D.C., and Sydney, Nova Scotia.*

Deductions were made from continuous series of equivalent height measurements which indicate that the ionization decreased to about forty per cent of its normal value at about eclipse maximum.

(2) *Observations made by J. P. Schafer and W. M. Goodall at Deal, N. J.*

Deductions were made from a continuous series of equivalent height measurements that the ionization reached a minimum within three or four minutes after optical totality.

Optical Eclipse. Region F_2

(1) *Observations made by D. C. Rose at Kingston, Canada.* (*Canadian Journal of Research*, vol. 8, January, (1933).)

The critical penetration frequency method of measuring maximum ionization was used. It was found that fifteen minutes before totality the penetration frequency dropped considerably, returning to its normal value about forty-five minutes after totality. A decrease in ionization of over thirty per cent was observed.

(2) *Fading and signal strength measurements made in Canada on commercial transmissions.* (*J. T. Henderson and D.C. Rose.*)

Observations were carried out at the Marconi transatlantic receiving station at Yamachiche, P.Q. The results may be summarized as follows:

(a) Signals from WDD, Long Island,
7.5 megacycles: no abnormal effect.

(b) Signals from VE9GW at Bowmanville, Ontario.
6.1 megacycles: abnormal fall of signal intensity between 2005 and 2030 G.M.T.

(3) *Observations made by Kirby, Berkner, Gilliland, and Norton at Washington, D.C.*

No abnormal variations of the critical frequency of F_2 region were observed. Since these observers consider that the critical frequency of this region is determined by absorption limitation and not by electron limitation they are of opinion that their results do not preclude the occurrence of a diminution of ionization during the optical eclipse.

(4) *Observations made by Kenrick and Pickard at Seabrook Beach, N. H.* (Proc. I. R. E., vol. 21, pp. 546–567; April, (1933).)

The equivalent height of reflection on a number of frequencies was recorded. On the frequencies of 3.5 and 4.5 megacycles two height maxima, one before and one after totality, were observed. These maxima occur at approximately fifty per cent totality. No such effects were obtained on control days.

(5) *Observations made by J. P. Schafer and W. M. Goodall at Deal, N. J.*

A continuous series of equivalent height measurements disclosed no changes of ionization which can be identified as an eclipse effect. No importance is attached to the occurrence of a large increase of equivalent height thirty minutes after totality since somewhat disturbed magnetic conditions obtained and similar variations were observed at random times in the interval comprising two days before to two days after the eclipse.

Corpuscular Eclipse.

(1) *Special ionospheric measurements made in Canada and the U.S.A.*

No evidence of a corpuscular eclipse was obtained by the groups of workers (see above) at

(a) Vankleek Hill, Ontario.
(b) Kingston, Canada.
(c) Washington, D.C.
(d) Sydney, Nova Scotia.
(e) Deal, N. J.

(2) *Observations made by E. F. W. Alexanderson at Conway, N. H.*

Signals from Schenectady on thirty-five meters, 200 miles away, were observed and found to disappear almost wholly during the two hours preceding the optical eclipse of the sun. On the other hand thirty-meter signals from Germany were at a maximum during the same period. This observer considers that the results constitute a complete proof of the theory of the electronic eclipse.

(3) *Observations made by H. R. Mimno and P. H. Wang at Harvard University, Cambridge, Mass.* (Proc. I. R. E., vol., 21, pp. 529–546; April, (1933).)

Measurements of the equivalent height of reflection were made on a wavelength of eighty-three meters. The height record was found to exhibit two maxima, one forty minutes before totality and another forty minutes after totality. The authors say "This strongly suggests a corpuscular effect on the high layer although we are not yet willing to rule out other possibilities."

(4) *Effect of solar eclipse on audio-frequency atmospherics, by E. T. Burton and E. M. Boardman.* (*Nature*, January 21, (1935).)

Although the chief effect noticed was correlated with the optical eclipse, evidence of a minor effect of corpuscular radiation was obtained.

(5) *Observations by H. E. Paul in Germany.*

Wolf has reported a regular and distinct increase of ionization beginning at sunset and reaching a maximum between 2000 and 2200 (region F). On the day of the eclipse this evening effect set in one hour later than on the preceding days and disappeared about one hour earlier. It is, however, doubtful whether this effect can be attributed to the corpuscular eclipse since similar anomalies occurred on September 6 and 18.

(6) *Observations made at King's College, London, by F. W. G. White.*

Continuous observations on echoes and determinations of equivalent heights were made on sixty-six meters. These were made in the evenings from about 1600 to 2230 B.S.T. on August 30 to September 2, inclusive.

On August 30 and on September 1 and 2 there was more intense region E ionization than on August 31. Another feature of the results was that the temporary increased group time separation between the two F components which occurred each evening at about 1820 was much more marked on August 31 than on the two succeeding days.

(7) *Observations made at Slough Radio Research Station, England.*

Particular attention was paid to region E ionization and an abnormally low value was noted at 1830 G.M.T., a condition which did not show on the control days. The argument for the corpuscular effect is weakened by a subsequent increase of ionization between 1830 and 1900 which is paralleled by observations on the day preceding the eclipse.

(8) *Observations made at Cambridge, England, by J. A. Ratcliffe.*

The following observations were made:

(a) Equivalent heights of reflection for 70-meter and 100-meter waves.

(b) Intensity of downcoming waves of 100 meters and 356 meters.

No differences were observed between the eclipse day and the control days which could not be explained as due to the ordinary fluctuations normally observed. This applies to the height of region F meas-

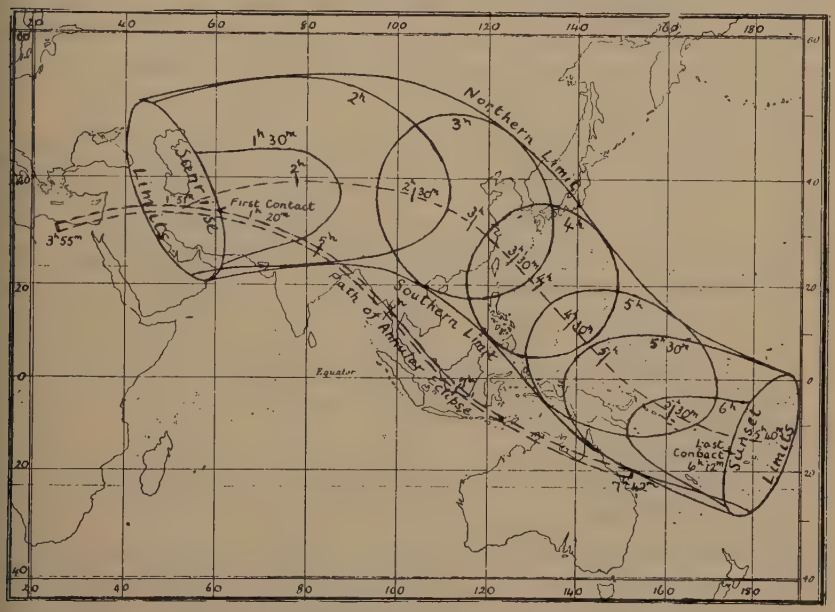


Fig. 2—Track of hypothetical corpuscular eclipse, August 21, 1933.

ured on 100 and 70 meters and to the intensity of the downcoming waves on 100 and 356 meters. It was, however, noticed that in the case of the equivalent height observations on 70 meters the ordinary ray component penetrated F region at 2130 on August 31 and at 2215 on both August 30 and September 1.

(9) *Observations made in H. M. Signal School, Portsmouth, England, by C. E. Horton and J. F. Coales.*

The apparatus was situated at Nutbourne (latitude 50°51′N, longitude 0°52′W) and observations were made of the apparent bearing of Daventry 5XX ($\lambda = 1500$ meters). During the day the bearing is sensibly constant but during conditions of "night effect" it changes

continuously. The apparatus was considered sufficiently sensitive to detect the presence of a reflected wave only 1/1000 of the intensity of the direct wave.

Measurements of the apparent bearing were made on August 30 and 31 and on September 1 from 1600 to 2100 B.S.T. These show that "night effect" set in two hours before sunset on all three days. No evidence of any change in the downcoming ray was noted on August 31 such as could be ascribed to the corpuscular eclipse.

Here it should be noted that the effects of an eclipse at 1930 and after would be masked by the normal operations of "night effect." On the other hand, a corpuscular eclipse giving rise to considerable changes of ionization would most probably have been detected at any time before 1815.

(10) *Observations on WQU (U.S.A.) received in London by G. C. Allen*

August 31 is reported as being an abnormal day from transatlantic signals of 31.75 meters, signals being higher in intensity than on days preceding and succeeding. A marked increase of signal level was noticed from 1959 to 2005. (B.S.T.)

(11) *Observations made in Japan on signal strength of British and American stations.*

No effects attributable to an optical or corpuscular eclipse were observed.

(12) *Observations on atmospherics at Jablonna, Tromsø, and Bear Island. (J. Lugeon.)*

No effects attributable to the corpuscular eclipse were observed.

(B) Annular Eclipse in India on August 21, 1933

Observations made by S. K. Mitra and others in Calcutta. (*Nature* September 16, (1933).)

Measurements were made by the critical frequency method for both E and F regions. It is concluded that "ultra-violet light is at least one of the agencies producing ionization of region E and that the corpuscular rays have little or no effect." The observations indicate a minimum in ionization of F region, a little over two hours before eclipse center, which was not paralleled on either of the control days August 20 and 22.

(C) Eclipse of February 14, 1934 at Losap Island (South Pacific)

(1) *Observations made by K. Maeda.* (*Report of Radio Research in Japan* vol. 4, no. 2, p. 89, (1934).)

It was found that the ultra-violet radiation from the sun is the prominent agent of atmospheric ionization and that the effect of neutral corpuscles is only slight, ending earlier on region F than on region E.

(2) *Observations made by T. Minohara and Y. Itô.* (*Report of Radio Research in Japan*, vol. 4, no. 2, p. 51, (1934).)

A marked decrease in ion density in region E was observed coinciding with the optical eclipse. The ion density of region F also diminished with the progress of the eclipse, there being a marked increase in the equivalent height about thirty minutes before and after totality.

As the frequency employed was not suitable for the purpose the effect of a corpuscular eclipse on region E could not be tested. Although the frequency used was suitable, no effect of a corpuscular eclipse on region F was observed.

Discussion of Results.

(a) *Eclipse of 1932*

The experimental evidence shows very definitely that ultra-violet light is to be regarded as the principal ionizing agency for region E, the minimum ionization values reached during optical totality being given by the Canadian and American observers as forty-two and thirty per cent, respectively. Chapman and Miller have determined theoretically the expected variation of ionization during the eclipse in Canada, assuming ultra-violet light as the sole ionizing agent and assuming the degree of recombination compatible with Appleton's daily variation curves for region E. The results agree closely with Henderson's eclipse graph of ionization and show that there is no need to attribute any part of the residual forty per cent electron content at totality to another ionizing source.

The eclipse observations also show that ultra-violet light is the principal ionizing agency for the shelf region (F_1) since the observations in Nova Scotia indicated a minimum value of forty per cent of normal coinciding approximately with optical totality. We may safely say that the calculations of Chapman and Miller apply here similarly and therefore conclude that there is no need to consider any ionizing agency other than ultra-violet light for region F_1.

For region F_2 correspondingly definite conclusions cannot be drawn. During the three days before the eclipse a magnetic storm, which was known to be in progress, had very noticeable effects on the upper ionized region. Conditions were therefore not normal. Nevertheless it may be noted that the observations at Kingston have been inter-

preted as indicating a reduction of thirty per cent from normal ioniz tion at totality while short-wave signals received at Bowmanville wer found to be abnormally weak during the optical eclipse. The observa tions at Seabrook Beach also showed anomalous variations of equiva lent height symmetrically situated with respect to the optical eclips On the other hand, the observations at Washington did not show an optical eclipse effect, though the observers are of opinion that, due t the unreliability of the measurement of F_2 region critical frequenci the results do not preclude its occurrence. The observations at De also showed no changes of ionization which could be identified as a eclipse effect. Taking the results as a whole, therefore, it appears as we can conclude that ultra-violet light is responsible for at least part of region F_2 ionization, but it is very desirable that the matte should be investigated, with perhaps improved technique, in futu eclipses.

With regard to the effects of a corpuscular eclipse we need n consider any region other than F_2. Here the evidence is a little co flicting. Fairly definite evidence of an effect is claimed by observers a Conway, New Hampshire, and Cambridge, Massachusetts; bu other observers situated in various parts of the world obtained n effect. It seems clear that the matter must still be regarded as *sub judi* and further work on the subject is very desirable.

(b) *Eclipse of 1933*

In the case of the eclipse at Calcutta evidence for an ultra-viol light control of region E ionization was obtained. An anomalous effe which might have been corpuscular in origin was obtained for regio F_2.

(c) *Eclipse of 1934*

In the case of the eclipse at Losap Island conclusive evidence of a ultra-violet effect on both regions E and F was obtained. The concl sions drawn by different authors concerning the effects of a corpuscul eclipse are conflicting.

Addendum

At meetings of the Plenary Congress of the International Unio for Scientific Radiotelegraphy held in London in September, 1934, th above document was discussed, and the following resolutions on th propagation of waves adopted by the Commission:

(1) That charts of the optical and corpuscular paths of future eclip should be prepared in advance.

(2) That concentration in the future should be made on region F_2 while some attention should also be given to the intermediate region.

(3) That attempts be made to standardize the form in which results are submitted.

(4) That the proposed Permanent Committee on Ionospheric Observations should undertake the organization of special observations during eclipses, including the making of applications to administration for the financial grants necessary to carry out the work.

The personnel of the Permanent Committee on Ionospheric Observations, approved by the International Scientific Radio Union, is as follows:

Professor E. V. Appleton, Great Britain, President; Major R. Bureau, France; Dr. D. La Cour, Denmark: Dr. J. H. Dellinger, U.S.A.; Mr. R. Naismith, Great Britain; Dr. B. van der Pol, Holland; and Mr. R. A. Watson Watt, Great Britain.

Proceedings of the Institute of Radio Engineers
Volume 23, Number 6 *June, 1935*

DIURNAL AND SEASONAL VARIATIONS IN THE IONOSPHERE DURING THE YEARS 1933 AND 1934*

By
J. P. Schafer and W. M. Goodall
(Bell Telephone Laboratories, Inc., Deal, New Jersey)

Summary—*The most important results of daily ionospheric measurements made at Deal, New Jersey, latitude 40° 15′ N., longitude 74° 02′ W., over the period from March, 1933, to May, 1934, are given in this paper and may be summarized as follows:*

1. There was a definite correlation between the noon value of ionic density of the F_1 region and magnetic disturbances, a decrease in ionic density being obtained on magnetically disturbed days.

2. The noon value of ionic density of the E and F_1 region attained a maximum in summer and a minimum in winter whereas the reverse condition, of minimum in summer and maximum in winter, was found for the F_2 region.

3. The time of maximum ionic density of the F_2 region varied with the seasons of the year, occurring near noon in winter and near sunset in summer.

The paper also shows a series of virtual height contour maps for the four seasons of the year.

Introduction

In previous publications giving the results of investigations of the ionosphere which we have made employing the radio pulse method,[1] attention has been directed to special experiments not involving routine measurements. There are important factors, however, such as seasonal and diurnal variations of ionization which can be discovered only by repeated observations extending over long periods of time. It is the purpose of this paper to report the results of such tests made during the years 1933 and 1934.

As a result of these tests we have obtained data which give us a better understanding as to the complex nature of the composition and behavior of the ionized regions as found at Deal, N. J., (latitude 40°15′ N., longitude 74°02′ W.) Among the questions partially answered may be listed the following:

(1) How does the virtual height of the various regions vary with time of day, season of the year, and frequency?

(2) What are the diurnal and seasonal variations of ionization in these regions?

* Decimal classification: R113.61. Original manuscript received by the Institute, February 13, 1935. Presented before Ninth Annual Convention, Philadelphia, May 30, 1934.

[1] "Kennelly-Heaviside layer studies employing a rapid method of virtual height determination," Proc. I.R.E., vol. 20, pp. 1131–1149; July, (1932). The method at present used is essentially the same as described in this article except that the transmitter and receiver are now located in the same room.

(3) What correlation, if any, exists between the ionization or ionization variations of these regions and magnetic disturbances?

Experimental Results

During a large part of the time from March, 1933, to April, 1934, a virtual-height versus frequency curve was obtained near noon for

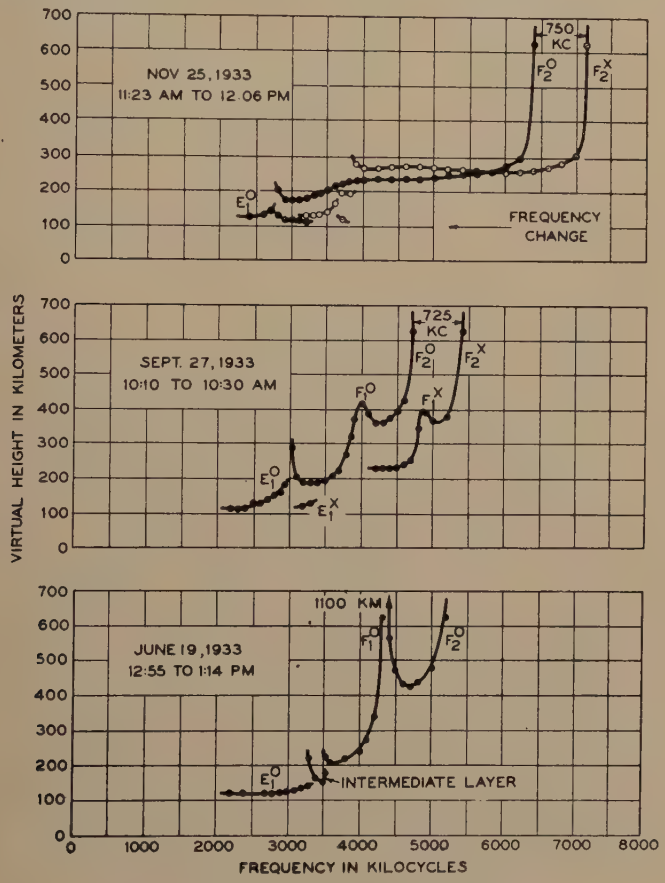


Fig. 1—Virtual height versus frequency.

practically every day of the year. This type of curve is illustrated in Fig. 1.

The three curves shown are typical examples of midday conditions for various seasons of the year; viz., summer, autumn, and winter. A number of features of these curves may be pointed out, some of which are common to all the curves and others peculiar to one curve only. In the first place it will be noted that all curves begin with virtual

heights of the order of 100 to 125 kilometers for the lower frequencies This indicates that reflection is occurring from the E layer. As the frequency is increased a point is reached where there is a break in the curve and reflections then occur at some higher value of virtual height The point at which this break occurs is termed the critical ionization frequency of the E layer. For the September and November curves the higher values of virtual height above the E layer represent reflections from the F_1 region at values near 200 kilometers. For the June curve there is apparently an intermediate reflecting region[2] between the E and F_1 regions from which reflections occur before a jump to the F_1 region is obtained. As the frequency is still further increased another discontinuity in the curve is observed at a frequency near 4000 kilocycles. This represents the frequency at which the wave penetrates the F_1 region and beyond which reflections occur from the F_2 region This frequency is termed the F_1 critical frequency. This break or discontinuity is found in the daytime but not at night and is more pronounced in the summer than in winter. The latter fact may be noted on these three examples. As the frequency is still further increased a point is reached where another discontinuity is reached and beyond which no reflections are usually obtained. This is the critical ionization frequency of the F_2 layer. It will be noted that for the September and November curves there is almost an exact image of the first part of the curve displaced from it by approximately 750 kilocycles. This duplication is due to magnetic double refraction and represents the two components of the received wave which are circularly polarized in opposite directions.[3] These two components have been termed the ordinary and extraordinary rays, and in our work we have termed them the "*O*" and "*X*" components, respectively. When the two components have widely separated virtual height values for a given frequency as in the curves of September 27, it is easy to follow them both with the ordinary receiver. When the two components are close together and the curves cross each other as in the curves of November 25, it is not so simple. We have constructed a "polarized" receiver[4] employing two similar horizontal antennas at right angles to each other for the pur-

[2] This intermediate region is probably the M region whose presence was reported in *Nature*, June 3, (1933), but it is difficult to fix its location because the virtual height of this region gradually decreased through the day from values near 200 kilometers at 9 A.M. to heights near 125 kilometers at 5 P.M. See contour map of Fig. 7.

[3] Appleton and Builder, *Proc. Phys. Soc.*, vol. 45, p. 208; March, (1933).

[4] This polarized receiver is essentially the same as that of Ratcliffe and White, *Phil. Mag.*, ser. 7, vol. 16, p. 125; July, (1933), except that two horizontal-dipole antennas were used instead of loops and the method of combining the antenna outputs was somewhat different.

pose of separating the two components, and this was used in obtaining the November data.

The X component is usually much weaker than the O component and in the case of the curve of June 19 it could not be found even with the full gain of the receiver. This is frequently the case in summer.

As the values of critical frequencies give a measure of the maximum ionic density of the various layers a study of their variations with time is of considerable importance. Fig. 2 shows how the average critical

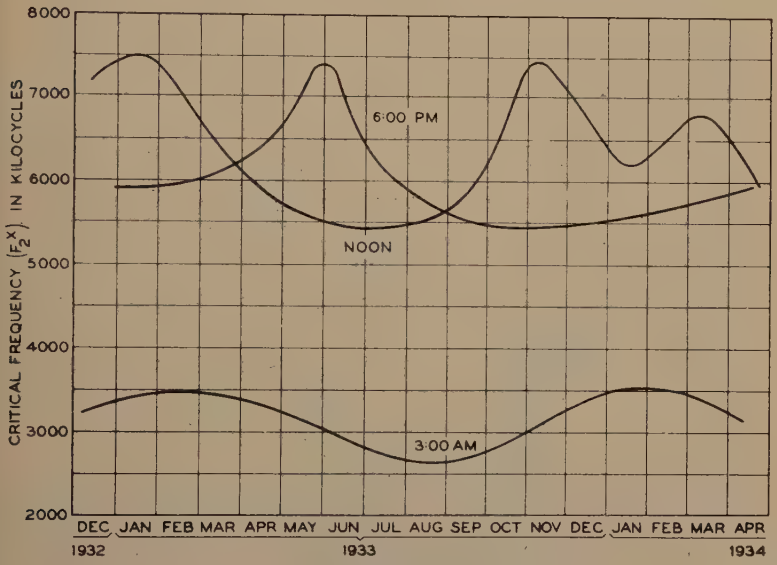


Fig. 2—Curves showing the seasonal variations of the *average* value of critical ionization frequency for the F_2 layer.

frequency value of the X component for the F_2 layer varies with the seasons of the year (1933–1934) at different times of the day, and suggests that the ionization in this layer varies in a different manner than would be expected on the basis of solar illumination. At noon the maximum occurred in winter rather than summer. At or near sunset the maximum occurred in summer[5] and at 3 A.M. the maximum again occurred in winter. No entirely satisfactory explanation has been brought forth for these phenomena but it seems to us that no single agency or mechanism can be responsible for these effects.

[5] Other investigators have pointed out this summer sunset phenomenon; see H. E. Paul, *Hochfrequenztechnik*, March, (1933), who speaks of the "evening concentration" in summer; and Kirby, Berkner, and Stuart, PROC. I.R.E., vol. 22, pp. 481–522; April, (1934), who disclosed this phenomenon in 1932 but who have suggested that the summer sunset maximum of F_2 critical frequency may not indicate a maximum of ionic content but may be due to a change in absorption.

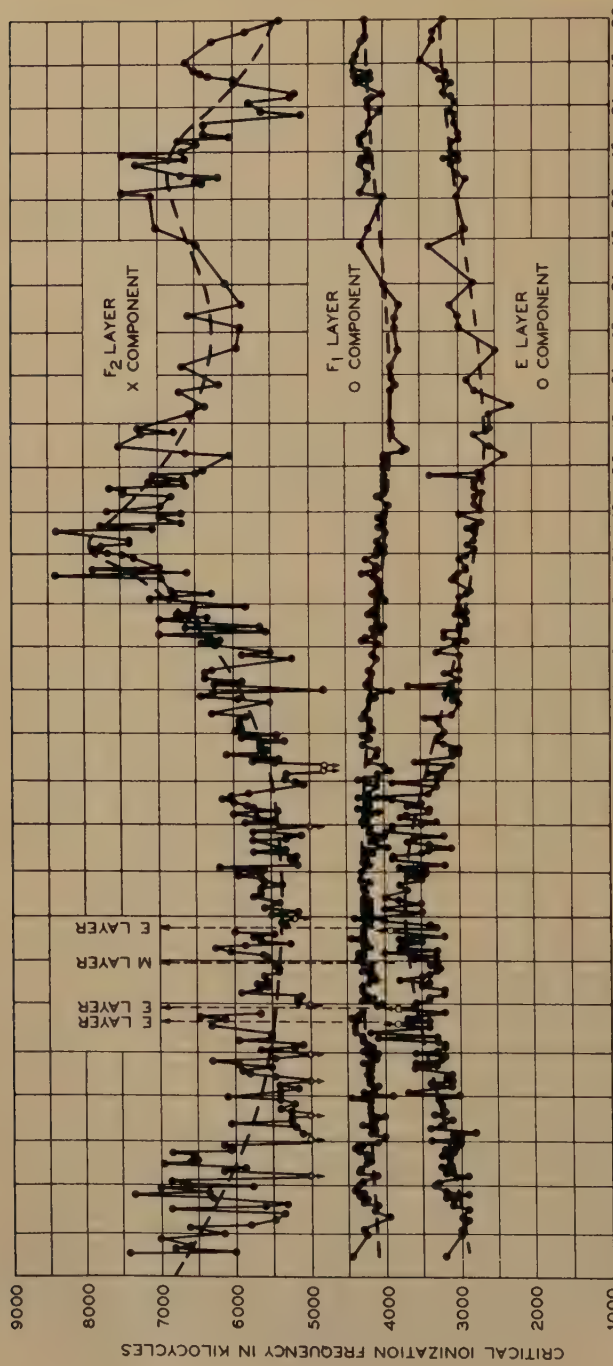


Fig. 3—Daily and seasonal variations of the noon value of critical ionization frequencies for the E, F_1, and F_2 layers. The open points with arrows shown for some days indicate that the actual value of critical frequency was not determined, but was either greater or less than the values marked.

Fig. 3 shows the manner in which the *noon* values of critical ionization frequency (f_c) for the E, F_1, and F_2 regions vary from day to day and with the seasons of the year. It must be remembered that some of the phenomena observed may be peculiar to the years 1933–1934 and that other years may disclose other seasonal variations. The lower curve represents the variation of the *O* component for the E layer and indicates that the ionization reaches a maximum in summer and minimum in winter. As the ionic density is proportional to f_c^2 for the *O* component the difference between maximum and minimum ionic density for the average curve is the ratio[6] of $(3700/2650)^2$ or 1.95.

The second curve represents the variations in the *O* component for the F_1 layer and reaches a maximum and minimum in phase with that for the E region, with a ratio[7] of summer-to-winter average of $(4300/3900)^2$ or 1.22.

The third curve represents the variations in the *X* component for the F_2 layer and as was said before reaches a maximum in winter and a minimum in summer. The *O* component of this layer varies in the same manner but at a frequency approximately 750 kilocycles lower. The *X* component was chosen as an illustration because it represents the highest frequency at which reflections are normally obtained, and also because the *O* component for this layer frequently has values of critical frequency very close to that for the F_1 layer, which would make the two curves difficult to follow. The curve of F_2 also illustrates the large day-to-day variations frequently found. It will be noted that there were two maxima[8] in F_2 critical frequency, one near the beginning of November, 1933, and the other near the beginning of March, 1934.

These three curves seem also to confirm the belief which had already been strengthened by observations during the solar eclipse of 1932, that the principal ionizing agency of the E and F_1 regions is the ultra-violet light from the sun while they suggest that an important agency or mechanism causing the ionization in the F_2 layer is from some other more-or-less random source.

If a large number of virtual height versus frequency curves such

[6] Values given by other observers are: 2.2 by E. V. Appleton, *Proc. Roy. Soc.*, A, vol. 141, (1933), and 1.3 by Kirby, Berkner and Stuart, PROC. I.R.E., April, (1934).

[7] A value of 1.4 is given by Kirby, Berkner, and Stuart., PROC. I.R.E., April, (1934).

[8] That these maxima were actually present in this year, although there are not enough data available to say whether they will be present every year, seems to be confirmed by the fact that similar curves for 1933–1934 recently shown by Kirby and Judson of the Bureau of Standards, also indicated the presence of these same two maxima. Both the Bureau of Standards paper and that of the writers were presented before the Ninth Annual Convention of the Institute, May 30, 1934.

as those shown in Fig. 1 are obtained on any one day it is possible to draw another type of curve which we have termed a virtual-height contour map. Figs. 4, 5, 6, 7, and 8 show contour maps[9] for the four seasons of the year, numbers 4 and 8 being for the spring seasons of 1933 and 1934, respectively. These contour maps illustrate the diurnal variations which are found in the various layers of the ionosphere and require considerable study in order to digest their story thoroughly

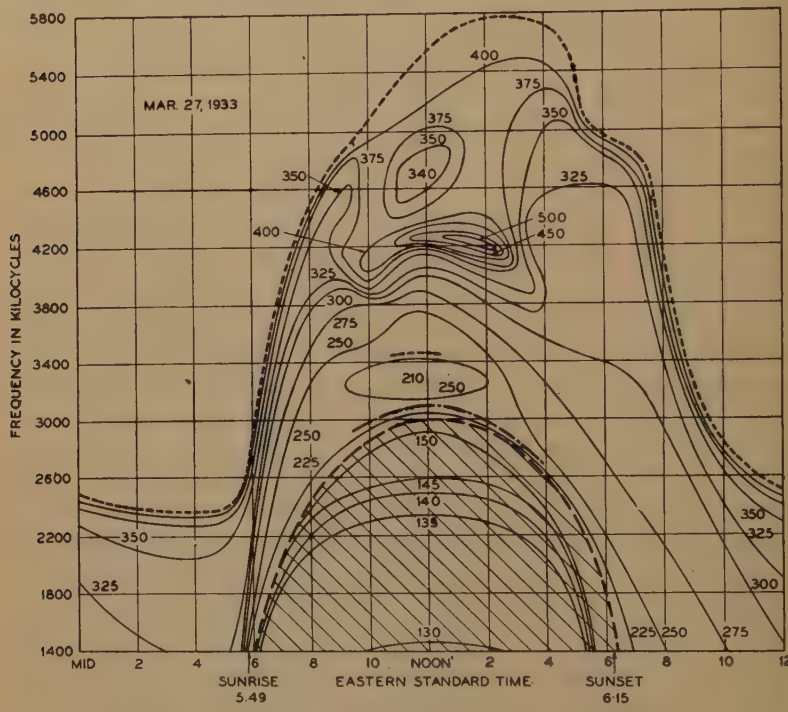


Fig. 4—Virtual height contour map for spring, 1933.

since each one represents hundreds of readings. The *O* component only is shown for the sake of simplicity.

Some of the principal points to be observed may be itemized as follows:

(1) The dashed lines represent the critical frequency boundaries between layers;

(2) An intermediate layer is formed at various times between the E and F region;

[9] The contour map of Fig. 4 has already been published in *Nature*, September 30, (1933), where much of the material in this paper has already been summarized.

(3) There is a tendency for a third division in the lower part of the F_2 region particularly on the map of September 27 (Fig. 6.);

(4) The critical frequency and therefore the ionic density of the E and F_1 regions is a maximum near noon for all seasons.

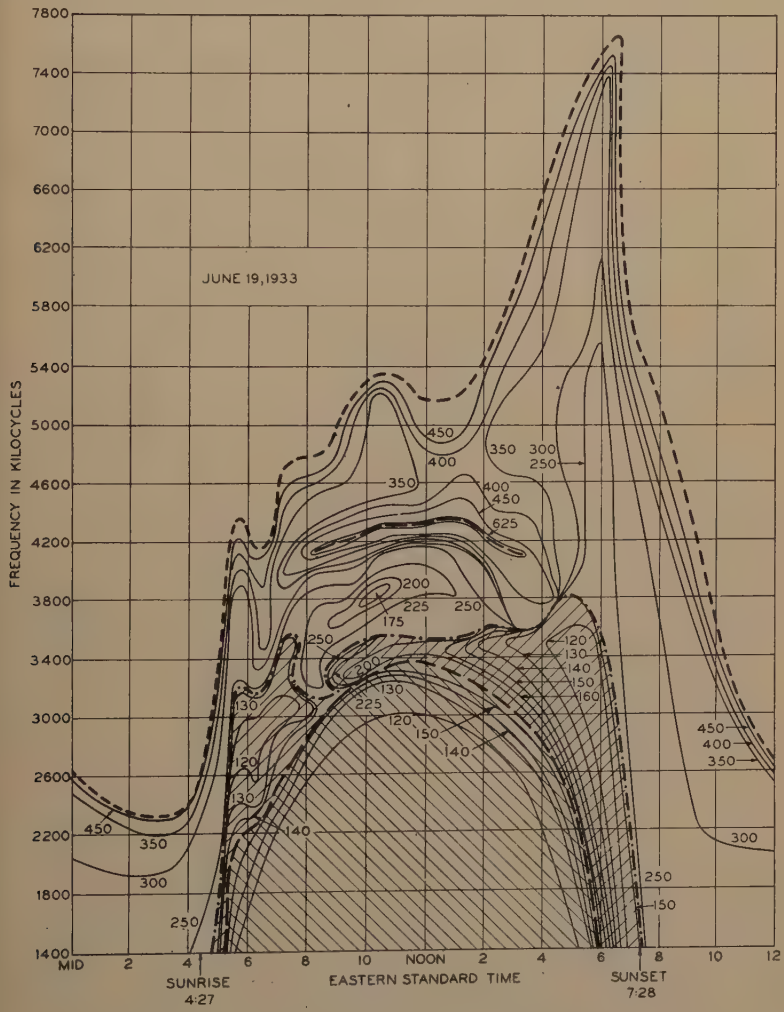


Fig. 5—Virtual height contour map for summer, 1933.

(5) There is an evening increase in F_2 critical frequency in the summer curve (Fig. 5).

(6) There is great similarity between the two spring maps which were obtained one year apart (Figs. 4 and 8).

(7) There is considerable similarity between the autumn and spring maps; which would logically be expected due to the similarity in solar conditions (Figs. 6 and 8).

(8) The summer map is much more complex than the winter map (Figs. 5 and 7), primarily due to the pronounced discontinuity between the F_1 and F_2 layers in the former.

From all the work which has been done by various experimenters in latitudes near that of Deal, Washington, and London no very

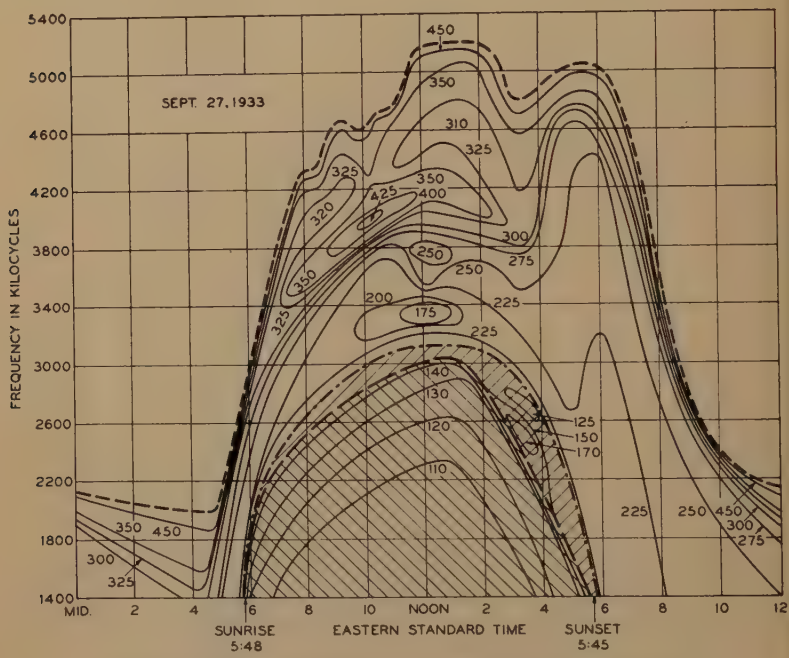


Fig. 6—Virtual height contour map for autumn, 1933.

marked correlation has been found between the virtual heights and ionization of the various layers, and magnetic disturbances. During severe storms the general tendency seems to be for an increase in absorption together with a scattering or splitting effect which manifests itself by the large number of reflections returned at slightly different virtual heights and which makes it difficult to distinguish one layer from another. During moderate storms it is usually difficult to tell whether a storm is in progress from qualitative observations of the reflections. If magnetic conditions have any characteristic effect on the ionization of the various layers, it would be expected that this fact would show up in the plot of the critical frequencies of Fig. 3 when com

pared to a plot of magnetic conditions over the same period of time. Such a correlation has been sought but none was found in the critical frequency of the E layer and the F_2 layer.

For the F_1 layer, however, there seems to be a rather definite trend for a reduction in critical frequency, which would mean a reduction in maximum ionic density of this layer, on days of magnetic disturbances. Fig. 9 illustrates the type of correlation found. The daily

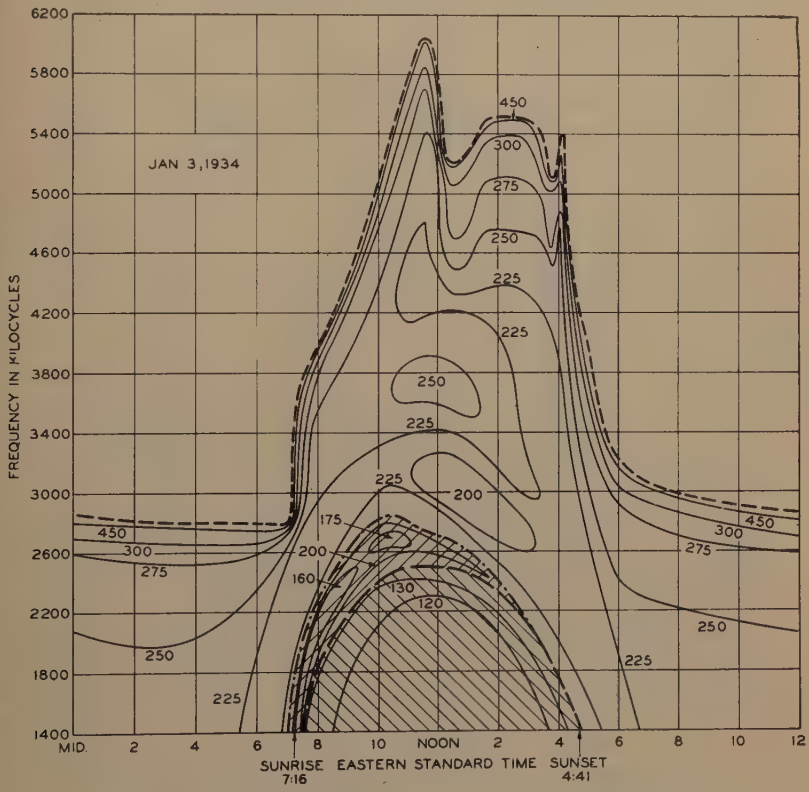


Fig. 7—Virtual height contour map for winter, 1933–1934.

noon value of F_1° has been plotted for a six-month period. Superimposed upon this curve is plotted the variation in earth potential as measured at Deal. It is known that variations in earth potentials are very closely related to magnetic variations, and as continuous records of earth potential variations are available at Deal, they were used for this purpose. The value of earth potentials used is the maximum variation for the particular day plotted, which has been found to be very closely related to the degree of magnetic disturbance. The two curves

follow each other very closely on the whole, and while not giving an exact correlation indicate that there is a definite reduction in $F_1°$ on magnetically disturbed days. At least there has been no occasion during the period of our measurements when the opposite effect has been found of an appreciable increase in ionic density of the F_1 layer on days of magnetic disturbances.

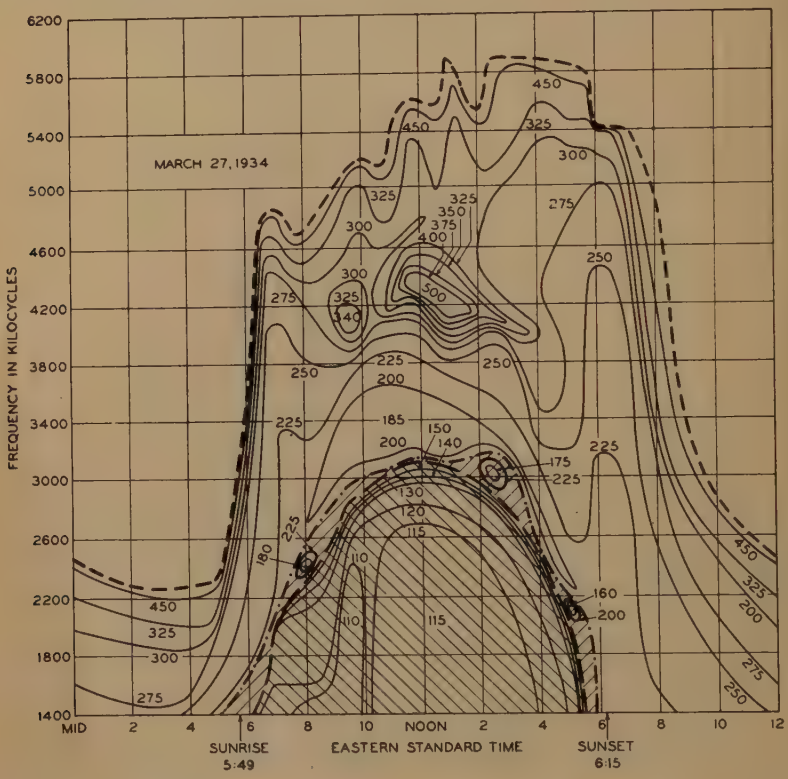


Fig. 8—Virtual height contour map for spring, 1934.

It would be interesting to speculate as to the significance of this fact. The F_1 layer has reduced ionic content during magnetic storms, and since this layer is believed to be mainly produced by ultra-violet light, the natural inference to draw is that the ultra-violet light is lessened at such times. This conclusion would be inconsistent with other observations, however, such as the failure to observe a similar correlation in the E layer, which also seems to be due to ultra-violet radiation, and the fact that the longer wave ultra-violet radiation, which is measured at low altitudes, is greater on the average during

times of maximum solar disturbance such as occurs in the eleven-year sun-spot cycle.

The reduction in ionic density of the F_1 layer during magnetic storms however, is only a relatively small amount of the total, never greater than 20 per cent, and it may be that these variations are due to changes in other solar emanations, which normally are a relatively minor factor in F_1 layer ionization, and not to a reduction in the principal ionizing agency which is believed to be ultra-violet light.

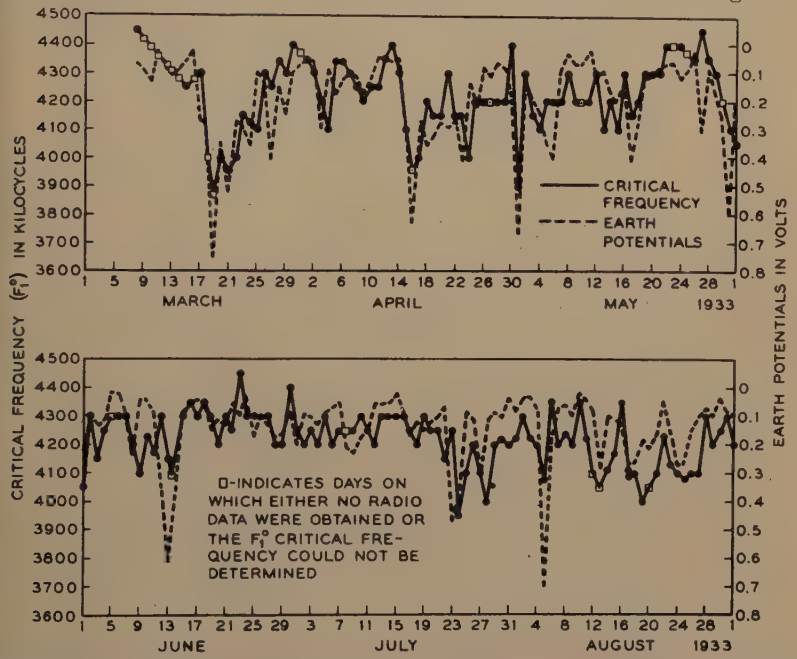


Fig. 9—Curves showing correlation between magnetic disturbances, as given by earth potential variations, and the ionization of the F_1 layer, as given by noon value of critical ionization frequency.

The reduced ionization at these times may also bear some relation to the observation that in transatlantic transmission with short waves, the most adverse effect is observed on the higher daylight frequencies. That is, if the normal band of frequencies lies between 18 and 12 megacycles, on magnetically disturbed days, the lower frequency is less affected than the higher. This might indicate that F_1 reflections play an important part in normal long-distance transmission and that on disturbed days ionization in the F_1 region is insufficient to deflect the higher frequencies. The whole process is very complicated, however, and any explanation, to be acceptable, must take account of many other aspects of transmission.

Correction

The following corrections have been received to the paper entitled "Designing Resistive Attenuating Networks," by P. K. McElroy, published in the March, 1935, issue of the PROCEEDINGS, pages 213–233, inclusive.

1. *Page 226.*
   a. The two equations at the top of the page should read:

$$u = a\left[Z\left(\frac{k^2+1}{k^2-1}\right) - 2\bar{z}\left(\frac{k}{k^2-1}\right)\right]$$

$$v = a\left[z\left(\frac{k^2+1}{k^2-1}\right) - 2\bar{z}\left(\frac{k}{k^2-1}\right)\right]$$

   b. Fourth line of the text is "the." Should be "that" so it will read: "Note that $\bar{z}[k/(k^2-1)]$ occurs in all three individual expressions" etc.

2. *Table IX (Insert).*
   a. Column 11, line 3. *For figure* 33.933 *read* 43.933.
   b. Column 11, line 4. *For figure* 19.455 *read* 29.455.
   c. Column 12, line 3. *For figure* 32.933 *read* 42.933.
   d. Column 12, line 4. *For figure* 18.455 *read* 28.455.

CONTRIBUTORS TO THIS ISSUE

Appleton, E. V.: Born 1892 at Bradford, Yorkshire, England. Graduated, St. John's College, Cambridge, 1914. University demonstrator in physics, Cavendish Laboratories, 1919–1924; Wheatstone professor of physics, University of London, 1924 to date. Received Morris Liebmann Memorial Prize, Institute of Radio Engineers, 1929. Vice president, Institute of Radio Engineers, 1932. Corresponding member, Prussian Academy of Science, 1934. President, International Scientific Radio Union, 1934. Fellow, Royal Society. Associate member, Institute of Radio Engineers, 1926; Fellow, 1931.

Ballantine, Stuart: Born September, 1897, at Germantown, Pennsylvania. Operator, Marconi Company, summers, 1913, 1914, and 1915; H. K. Mulford Company, bacteriologists, 1916; Bell Telephone Company of Pennsylvania, 1917; Expert Radio Aide, U. S. Navy, in charge of radio direction finder apparatus, 1917–1920. Studied mathematics at Drexel Institute, 1919; mathematical physics, graduate school, Harvard University, 1920–1921. With L. M. Hull organized technical work at Radio Frequency Laboratories, Inc., 1922–1923. John Tyndall Scholar in mathematical physics, Harvard University, 1923–1924. Privately engaged in scientific research, White Haven, Pennsylvania, 1924–1927. In charge of research division, Radio Frequency Laboratories, 1927–1929; president, Boonton Research Corporation, 1929–1935; president, Ballantine Laboratories, 1935. Received Morris Liebmann Memorial Prize, Institute of Radio Engineers, 1931; Elliott Cresson Medal, Franklin Institute, 1934. President, Institute of Radio Engineers, 1935. Fellow, American Physical Society and Acoustical Society of America; Member, Franklin Institute. Associate member, Institute of Radio Engineers, 1916; Fellow, 1928.

Case, Nelson P.: Born July 17, 1904, at Canon City, Colorado. Received B. A. degree in physics, Stanford University, 1924; E.E. degree, 1926. Geophysical research, 1926–1928; assistant physicist, Bureau of Standards, 1928–1929; research physicist, department of engineering research, University of Michigan, 1929–1931; engineer, Hazeltine Corporation, 1931 to date. Member, Phi Beta Kappa and Sigma Xi. Associate member, Institute of Radio Engineers, 1926; Member, 1931.

Chapman, Sydney: Born January 29, 1888, at Manchester, England. Received D.Sc. degree, Manchester; M.A. degree, Cambridge. Chief assistant, Royal Observatory, Greenwich, 1910–1914. Fellow and lecturer at Trinity College, Cambridge, 1913–1919; professor of mathematics, Manchester University, 1919–1924; Imperial College of Science and Technology, London, 1924 to date. Fellow, Royal Society; Royal Medallist, 1934. President, London Mathematical Society, 1929–1931; president, Royal Meteorological Society, 1932–1934; chairman, British National Committee for Geodesy and Geophysics, 1934. Nonmember, Institute of Radio Engineers.

Goldsmith, Thomas T., Jr.: Born January 9, 1910 at Greenville, South Carolina. Received B.S. degree in physics and mathematics, Furman University, 1931; graduate student, Cornell University, 1931 to date. Chemistry assistant,

Furman University, 1929–1930; physics assistant, 1930–1931; physics assistant, Cornell University, 1935. Nonmember, Institute of Radio Engineers.

Goodall, W. M.: Born September 7, 1907, at Washington, D. C. Received B.S. degree, California Institute of Technology, 1928. Technical staff, Bell Telephone Laboratories, 1928 to date. Associate member, Institute of Radio Engineers, 1929.

Harnett, Daniel E.: Born July 20, 1899, at Elmira, New York. Received B.A. degree, Columbia University, 1922; E.E. degree, 1925. Engineer, Pacent Electric Company, 1925–1927; superintendent, W. J. Murdock Company, 1927–1928; engineer, Acoustic Products Corporation, 1928; engineer, Hazeltine Corporation, 1929 to date. Associate member, Institute of Radio Engineers, 1925.

Johnson, J. Kelly: Born January 27, 1903, at Oskaloosa, Iowa. Received B.A. and B.S. degrees, Penn College, 1923; B.A. degree, Columbia University, 1924; B.S. degree, 1925; E.E. degree, 1927. Instructor in electrical engineering department, Columbia University, 1928–1929. Engineer, Silver-Marshall, 1929; engineer, Hazeltine Corporation, 1930–1934; chief engineer, Wells-Gardner and Company, 1934 to date. Member, Sigma Xi, Tau Beta Pi, and Epsilon Chi. Associate member, Institute of Radio Engineers, 1926; Member, 1935.

Richards, L. A.: Born April 24, 1904, at Fielding, Utah. Received B.S. degree, Utah State Agricultural College, 1926; M.S. degree, 1927. Physics laboratory instructor, Utah State Agricultural College, 1924–1925; research assistant, 1925–1927. Received Ph.D. degree in physics, Cornell University, 1931. Graduate assistant in physics, Cornell University, 1927–1929; instructor, 1929–1935. Research physicist, Battelle Memorial Institute, 1935. Member, Phi Beta Kappa Sigma Xi, and American Physical Society. Nonmember, Institute of Radio Engineers.

Schafer, J. Peter: Born October 29, 1897, at Brooklyn, New York. Received B.S. degree in electrical engineering, Cooper Union, 1921; E.E. degree, 1925. Member, technical staff, research department, Western Electric Company and Bell Telephone Laboratories, 1915 to date; New York City Laboratories, 1915–1922; Rocky Point Transatlantic Radiotelephone Station, 1922–1928; Deal, New Jersey, Radio Laboratories, 1928 to date. Associate member, Institute of Radio Engineers, 1924; Member, 1930.

Wheeler, Harold Alden: Born May 10, 1903, at Saint Paul, Minnesota. Received B.S. degree in physics, George Washington University, 1925. Postgraduate studies, physics department, Johns Hopkins University, 1925–1928; lecturer, 1926–1927. Assistant, Radio Section, Bureau of Standards, 1921–1922; assistant to Professor Hazeltine, 1923; engineer, Hazeltine Corporation, 1924 to date. Member, Sigma Xi. Associate member, Institute of Radio Engineers, 1927; Member, 1928.

Whitman, Vernon E.: Born April 30, 1900, at Washington D.C. Received B.Sc. degree in electrical engineering, Massachusetts Institute of Technology, 1922; M.Sc. degree in physics, 1924; M.A. degree in physics, Johns Hopkins University, 1926; Ph.D. degree in physics, 1928. Physicist, Bureau of Standards, 1923–1929; engineer, Hazeltine Corporation, 1929 to date. Associate member, Institute of Radio Engineers, 1931.

INSTITUTE SECTIONS

ATLANTA—Chairman, I. H. Gerks; Secretary, Philip C. Bangs, 23 Kensington Road, Avondale Estates, Ga.

BOSTON—Chairman, E. L. Chaffee; Secretary, Roland G. Porter, Northeastern University, Boston, Mass.

BUFFALO-NIAGARA—Chairman, L. E. Hayslett; Secretary, E. C. Waud, 235 Huntington Ave., Buffalo, N. Y.

CHICAGO—Chairman, Alfred Crossley; Secretary, J. Kelly Johnson, Wells-Gardner Company, 816 N. Kedzie St., Chicago, Ill.

CINCINNATI—Chairman, Armand Knoblaugh; Secretary, George F. Platts, Crosley Radio Corporation, Cincinnati, Ohio.

CLEVELAND—Chairman, Carl J. Banfer; Secretary, J. S. Hill, 3325 Beachwood Ave., Cleveland Heights, Ohio.

CONNECTICUT VALLEY—Chairman, J. A. Hutcheson; Secretary, C. B. De Soto, American Radio Relay League, 38 La Salle Rd., West Hartford, Conn.

DETROIT—Chairman, A. B. Buchanan; Secretary, E. C. Denstaedt, Detroit Police Department, Detroit, Mich.

LOS ANGELES—Chairman, H. C. Silent; Secretary, N. B. Neely, 1569 Munson Ave., Los Angeles, Calif.

NEW ORLEANS—Chairman, J. A. Courtenay; Secretary, C. B. Reynolds, Radiomarine Corporation of America, 512 St. Peter St., New Orleans, La.

PHILADELPHIA—Chairman, E. D. Cook; Secretary, R. L. Snyder, 103 Franklin Rd., Glassboro, N. J.

PITTSBURGH—Chairman, C. K. Krause; Secretary, H. V. Noble, c/o Gulf Research and Development Company, 327 Craft Ave., Pittsburgh, Pa.

ROCHESTER—Chairman, H. J. Klumb; Secretary, H. A. Brown, 89 East Ave., Rochester, N. Y.

SAN FRANCISCO—Chairman A. H. Brolly; Secretary, R. D. Kirkland, Mackay Radio and Telegraph Company, 22 Battery St., San Francisco, Calif.

SEATTLE—Chairman, R. C. Fisher; Secretary, C. E. Williams, 2340 Delmar Dr., Seattle, Wash.

TORONTO—Chairman, A. B. Oxley; Secretary, L. M. Price, Radio Valve Company of Canada, 189 Dufferin St., Toronto, Ont., Canada.

WASHINGTON—Chairman, E. K. Jett; Secretary, W. B. Burgess, 2900-26th St. N. E., Washington, D. C.

GEOGRAPHICAL LOCATION OF MEMBERS ELECTED APRIL 3, 1935

Transferred to the Fellow Grade

New York	Rochester, Stromber-Carlson Tel. Mfg., Co., 100 Carlson Rd.,	Graham, V. M.

Transferred to the Member Grade

Maryland	Baltimore, 3310 Windsor Ave.	Plummer, W. E.
New York	New York City, 2344 University Ave.	Taylor, S. G.
Pennsylvania	Philadelphia, 21 Gordon Lane, Chestnut Hill	Ellsworth, W. C.
	Pittsburgh, P.O. Drawer 2038	Noble, H. V.

Elected to the Member Grade

California	San Francisco, 57 Post St.	Metcalf, H. E.
New York	New York City, 90 West St.	Smith, M. T.
England	Chesham Bois, Bucks., 17 Woodside Ave.	Dobell, H.
Jamaica	Kingston, Telegraph Office, G.P.O.	Guilfoyle, T. J.

Elected to the Associate Grade

California	Culver City, 3847 Goldwyn Ter.	Kimball, H. R.
	Inverness, Box 167	Schoenfeld, E.
	La Canada, Route 1, Box 748 P.	Wachner, D. L.
	Long Beach, 115 E. 12th St.	Tapp, J. E.
	Los Angeles, 753 S. Bonnie Brae St.	Everett, F. A. M.
	Los Angeles, 1324 Calumet Ave.	Smith, C. D.
District of Columbia	Washington, 3500-14th St. N.W.	Jensen, J. O.
	Washington, 1332 Irving St. N.W.	Judson, L. H.
Illinois	Chicago, Radio Station WJJD, 201 N. Wells St.	Coleman, H. E.
	Chicago, 4349 W. 14th St.	Mages, M.
	Chicago, 6555 N. Campbell St.	Mitchell, D. H.
Kentucky	Owensboro, 124 W. 18th St.	Carter, M. D.
	Owensboro, 121 W. 23rd St.	Hammond, C. R.
Massachusetts	Cambridge, Box 27, Mass. Inst. of Technology	Greene, F. M.
	Ware, 16 Walnut St.	Fitzgerald, J. A.
Michigan	Detroit, 12731 Marlowe	Bascom, E. R.
	Detroit, 15880 Steel Ave.	Dudeck, P. H.
New Jersey	Camden, RCA Victor Company	Wendt, K. R.
	Hackettstown, 143 Main St.	Cortright, R. D.
New York	Brooklyn, 180 Gates Ave.	Phillips, J. J.
	Buffalo, 33 Condon Ave.	Horn, M. V.
	East Aurora, 55 Park Pl.	Andrews, R. W.
	New York City, 463 West St.	Corbin, J. E.
	New York City, 200 Broadway	Schatt, M.
	Schenectady, 13 State St.	Goodhue, W. W.
	Schenectady, General Engineering Lab., General Electric Co.	Muchow, A. J.
Ohio	Cincinnati, WKRC, Inc., Hotel Alms	Dieringer, F. A.
Pennsylvania	Philadelphia, Philadelphia Storage Battery Co., Ontario and C Sts.	Smith, D. B.
	Rutledge, P.O. Box 222	Clapp, R. G.
Texas	Beaumont, Seismo. Dept., c/o Sun Oil Co.	Grenader, P.
	Lubbock, 2413-14th St.	Hewett, R. C.
Wisconsin	Madison, 229 Van Deusen St.	Creutz, J.
	Milwaukee, 785 N. Cass St.	Naughton, G. J.
Australia	Camperdown, Victoria	Emeny, T. F.
Brazil	Rio de Janeiro, Rua da Carioca 45–3°	Labre, J., Jr.
Canada	Bowmanville, Ont., P.O. Box 297	Crowe, F. C.
Channel Islands	St. Peter-In-The-Wood, Guernsey, "Longfrie"	James, E. A.
China	Hongkong, 1 Hollywood Rd.	Chan, A.
	Hongkong, 231 Prince Edward Rd.	Derby, P. W.
Colombia	Medellin, c/o All America Cables, Apartado 121	Tarr, L. H.
England	Ealing, London W. 13, 16 Cranmer Ave.	Smith, S. J.
	Oakworth, Nr. Keighley, Yorks., "Inglenook"	Almond, R.
	Shelf, Nr. Halifax, Yorks., 73 Cooper Lane	Asquith, E.
Malta	Calafrana, R. A. F. Base	Swinney, E.
Mexico	Nuevo Laredo, Tam., Matamoros 1308	Cuesta, N., Jr

Elected to the Student Grade

California	Berkeley, 2418 Ashby Ave	Morrison, K. G.
	Palo Alto, Box 1301, Stanford University	Oliver, B. M.
Indiana	Terre Haute, 229 N. 5th St	Reedy, P. H.
Michigan	Detroit, 12093 Engleside	Abfalter, H. F.
Minnesota	Minneapolis, 531 Walnut St. S.E.	Baranovsky, C.
New Jersey	Camden, 1135 Haddon Ave	Schaevitz, H.
	Collingswood, 830 Stokes Ave	Moon, D. M.
	Moorestown, 308 E. 3rd St	Barbier, W. H.
	Union City, 512-37th St	Braun, H. C.
New York	Troy, 197 Hoosick St	Christaldi, P. S.
	Troy, 197 Hoosick St	Ferry, R. N.
Pennsylvania	Emsworth, 151 Center Ave	McConnell, R. H.
	Philadelphia, 7703 Hasbrook Ave	Senn, G. F.
Tennessee	Lebanon, Tarver Ave	Smith, G. G.

APPLICATIONS FOR MEMBERSHIP*

Applications for transfer or election to the various grades of membership have been received from the persons listed below, and have been approved by the Admissions Committee. Members objecting to transfer or election of any of these applicants should communicate with the Secretary on or before May 31, 1935. These applications will be considered by the Board of Directors at its meeting on June 5, 1935.

For Transfer to the Fellow Grade

Massachusetts	Cambridge, General Radio Company, 30 State St.	Shaw, H. S.

For Election to the Fellow Grade

New York	Schenectady, General Electric Company	Procter, J. A.

For Transfer to the Member Grade

Indiana	Indianapolis, 122 W. New York St.	Garstang, W. W.
New York	Hartsdale, Hartsdale Towers	Smith, S. B.
	New York City, 2 Horatio St.	Anderson, E. C.

For Election to the Member Grade

Massachusetts	Winter Hill, 149 Sycamore St.	Scott, H. H.
New York	Brooklyn, 18 Maple St.	Morton, A. R.

For Election to the Associate Grade

California	San Francisco, 224 Harriet St.	Baldwin, E. F.
Illinois	St. Charles, Operadio Manufacturing Company	McCraigh, J. F.
Iowa	Ames, 2611½ Knapp St.	Stewart, W. E.
Massachusetts	Newton, Raytheon Production Corp., 55 Chapel St.	Lowery, W. E.
	Springfield, 44 Colonial Ave.	Potter, E. H.
Michigan	Detroit, Detrola Radio Corp., 3630 W. Fort St.	Lichtman, S. W.
	Grand Rapids, 257 Lagrave Ave.	Sanford, L. C.
New Jersey	Bloomfield, Westinghouse Lamp Company	Moran, W. G.
	Camden, 3057 Carman St.	Briggs, A. S.
	Camden, 210 Cooper St.	Morgan, J. M.
	Camden, 1264 Langham Ave.	Teaf, J. H.
	Edgewater Park, Summer Ave.	Hyland, W. A.
	Glen Ridge, 42 Stephen St.	Potter, C. R.
New York	Brooklyn, 207 Park Pl.	Likel, H. C.
	Brooklyn, 102 Berkley Pl.	Phillips, R. K.
	Brooklyn, 1875 Stuart St.	Testan, P., Jr.
	LeRoy, Lapp Insulator Company, Inc.	Lapp, R. S.
	New York City, 218 W. 10th St.	Kinney, G. F.
	New York City, 807 Riverside Dr.	Wolff, S.
Ohio	Cincinnati, 2953 Colerain Ave.	Cooke, C. G.
Pennsylvania	Ardmore	Williamson, J. F.
	Bethlehem, 225 E. Broad St.	Heine, L. J.
	Carnegie, 90 Pilgrim Rd., Rosslyn Farms	Stark, R. E.
	Philadelphia, 522 W. Chew St.	Kelley, E.
	Pittsburgh, 215 Jacksonia St. N.S.	Rittman, F. L.
South Dakota	Pierre, P.O. Box 224	Gull, R. A.
Virginia	Norfolk, V.B.3.B., N.A.S.	Hargis, D. A.
Washington	Tacoma, 1325-6th Ave.	Picken, J. C., Jr.
Australia	Kensington, Sydney, 25 Winburn Ave.	Scott, A. W.
	Melbourne N. 3, University of Melbourne	Webster, H. C.
Austria	Graz, Universitat, Physikalisches Institut	Szekely, A.
Canada	Montreal, P.Q., c/o Northern Electric Company, 1261 Shearer St.	Sillitoe, S.
	Timmins, Ont., Box 592	Rowland, L. J.
England	Bexhill-on-Sea, Sussex, 19 Sea Rd.	Blackburne, A. F. N.
	Blackpool, Lancs., 7 Gordon Ter., Poulton-le-Fylde	Tweedale, A.
	Canterbury, Kent, 18 St. Georges St.	Bradford, R. W.
	Droitwich Spa, Worcs., 66 Tagwell Lane	Dew, W. E.
	London S.W. 1, c/o Grindlay and Company, Ltd., 54 Parliament St.	Min, M. K.
	Newport, I.O.W., The Bungalow, Shide Path, Shide	Carey, R. D.
	Purley, Surrey, Purley Radio, Ltd., 18 Tudor Ct.	Langford, S. C.
	Whitley Bay, Northumberland, Kendal House, 19 Mason Ave.	Sharp, A. V.
France	Brest, Finistere, 71 rue Jean Jaure	Haubert, A.
India	Bangalore, Dept. of Physics, Central College	Narasimhaiya, R. L.
	Baroda, Kothi Pole	Shah, C. C.
	Delhi, Famous Pictures, Chandin Chowk	Kanitkar, G. C.
	Nagpur, Budhawak Darwaja Circle No. 7	Badkes, D. J.

Scotland	Glasgow, 14 Belhaven Ter.	Jefferson, S.
South Africa	Durban, 60 Field St.	Battersby, P. R. A.
Spain	Madrid, Po Prado 40	Escritano, F. C.
Sweden	Lidingo, Nr. Stockholm, Aga-Baltic Radio A/B	Granqvist, C. E.
Territory of Hawaii	Honolulu, University of Hawaii	Miyake, I.

For Election to the Student Grade

California	Pasadena, 1301 E. California St.	Muller, C. R.
	Pasadena, 303 S. Chester Ave.	Pierce, J.
Idaho	Moscow, Delta Tau Delta	Byrne, M. E.
Kansas	Manhattan, 1031 Bluemont Ave.	Evans, R.
Michigan	Houghton, 96 Hubbell Ave.	Chudyk, A.
	Houghton, 109 Isle Royale St.	McArdle, B.
	Lincoln Park, 1288 Washington Ave.	Lawrence, S. C.
New Jersey	Jersey City, 2600 Boulevard	Boyajean, J. A., Jr.
	Pitman, 411 W. Holly Ave.	Hughes, E. T.
Oregon	Corvallis, 1565½ Monroe St.	Sasser, L.
Pennsylvania	Allentown, 1860 S. Wood St.	Bradley, W. E.
	Lansdowne, 234 Windemere Ave.	Tellier, J. C.
	Philadelphia, 6850 Chester Ave.	Herbster, M. O.
	Philadelphia, 3424 Walnut St.	Mode, D. E.
	Philadelphia, 5403 Willows Ave.	Stewart, F. F., Jr.
	Philadelphia, 6002 Oxford St.	Warshaw, J.
	Philadelphia, 5821 Ellsworth St.	Weaver, C. H.

OFFICERS AND BOARD OF DIRECTORS

(Terms expire January 1, 1936, except as otherwise noted)

President

STUART BALLANTINE

Vice-President

GEORG HEINRICH BARKHAUSEN

Treasurer	*Secretary*	*Editor*
MELVILLE EASTHAM	HAROLD P. WESTMAN	ALFRED N. GOLDSMITH

Directors

O. H. CALDWELL
V. M. GRAHAM
R. A. HEISING
J. V. L. HOGAN
L. M. HULL, *Junior Past President*
F. A. KOLSTER
GEORGE LEWIS
H. M. TURNER
A. F. VAN DYCK

SERVING UNTIL JANUARY 1, 1937

ARTHUR BATCHELLER
C. M. JANSKY, JR., *Senior Past President*
WILLIAM WILSON

SERVING UNTIL JANUARY 1, 1938

E. L. NELSON
HARADEN PRATT
L. E. WHITTEMORE

★

OLD-FASHIONED

SIMPLICITY

TELEPHONE SERVICE in this country is modern. It leads the world. Yet there is an old-fashioned simplicity about the Bell System. This applies to capital structure and financial methods as well as to the nation-wide plan of decentralized operation under centralized control.

The American Telephone and Telegraph Company has only one class of stock and that stock is not watered.

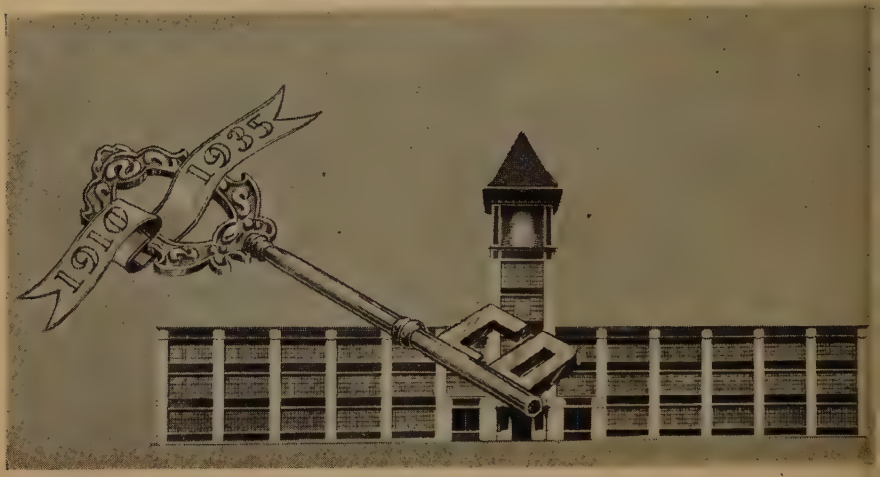
It has 675,000 stockholders living in every corner of the land. Their average holding is twenty-eight shares. No individual or organization owns as much as one per cent of the stock. There are no secret reserves or hidden assets.

This structure is not of recent origin, but dates back many years to the early days of the telephone. It has lived on because it is right and in the best interest of the public. It has been fundamental in making the Bell System a distinctive American business.

Research for the Bell System is carried on by Bell Laboratories. Manufacturing, purchasing, distributing by Western Electric. Both help in giving the country good, economical telephone service.

BELL TELEPHONE SYSTEM

When writing to advertisers mention of the PROCEEDINGS *will be mutually helpful.*



ACCEPT THIS KEY

EVERY so often a distinguished person gets a key to the city bestowed upon him . . . ticker tape fills the air and trumpets blare at the head of marching columns. To the members of the I.R.E., now assembled in convention, no clarion paean of victory sounds from the modest precincts of our plant . . . yet we offer you humbly and unostentatiously the key to our vaults of experience and knowledge.

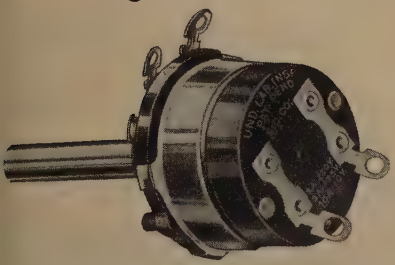
WHAT we have, we offer, simply, quietly. A record of experience in this industry that goes back twenty-five years. Two and a half decades of engineering development that have effected the evolution of a line of quality products. A tradition of service which has made the name Cornell-Dubilier a guarantee in every branch of the radio and electrical industries.

THIS is our welcome to the members of the I.R.E., in convention. "The doors to our wealth of experience, specialized knowledge and achievement are open to you." Engineers of the I.R.E. . . . *Accept This Key.* We offer it to you in simple honor.

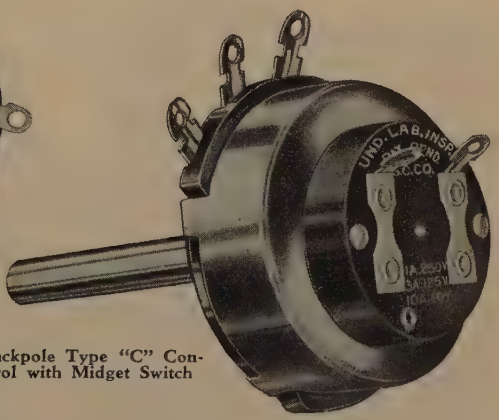
OVER ONE BILLION CONDENSERS SOLD SINCE 1910

CORNELL-DUBILIER
CORPORATION
4379 BRONX BOULEVARD • NEW YORK

Stackpole Presents a new Midget Control for Auto Radios

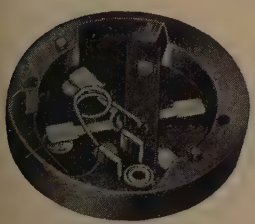


New Midget Control with line switch



Stackpole Type "C" Control with Midget Switch

Interior Midget switch (open)



Interior Midget switch (closed)

On behalf of modern design and engineering, you've repeatedly asked for a miniature control, with a dependable line switch, replete in all known advantages of larger size controls. You asked for it—our engineers went to work—and now after months of experimental work, we have it! A MIDGET CONTROL by STACKPOLE—100% accurate—not a single outstanding point of our larger controls is sacrificed.

The NEW MIDGET CONTROL is a "Natural" for the makers of the new Auto Radios where, at best, space is at a minimum. It's a "find" for the makers of modern household receivers—the line switch carries the APPROVAL of the UNDERWRITERS LABORATORIES.

Each terminal of the switch has two contacts—insuring POSITIVE CONTROL and LOWEST possible CONTACT DROP. MIDGET CONTROLS are available in Types "MB" and "MP." In applications where space is at a premium and our type "C" control is essential—the MIDGET SWITCH is recommended in place of our S-1 Type switch.

Write for detailed data on complete STACKPOLE line.

STACKPOLE CARBON COMPANY

St. Mary's, Pa. U.S.A.

A COMPLETELY COORDINATED

FROM THE MICROPHONE
LOUDSPEAKER

Only RCA has
this entire

RCA Velocity
Microphone

RCA Monitor Unit

RCA Speech
Input Panel

RCA MANUFACTURING

BROADCASTING SYSTEM

IN THE STUDIO TO THE IN THE HOME

undertaken responsibility

RCA High Fidelity Transmitter, Type 5-C

RCA Rectifier Tubes

RCA Power Radiotrons

RCA Receivers for Home, Auto, Boat, Train, 'Plane—Everywhere

CO., INC., CAMDEN, N. J.

The present trend toward rectangular instruments emphasizes Weston's leadership to a marked degree. Rectangulars were introduced by Weston over 10 years ago . . . and are today available in all standard sizes including the 3″ line.

Whether rectangulars are to be used because of their greater utility, or for purposes of design . . . or whether the need is for round or fan-shaped instruments . . . each requirement can be filled from the complete Weston line. *Weston dependability is available in any shape or form* . . . Weston Electrical Instrument Corp., 589 Frelinghuysen Avenue, Newark, N. J.

WESTON *Instruments*

When writing to advertisers mention of the PROCEEDINGS *will be mutually helpful.*

The Institute of Radio Engineers

Incorporated

330 West 42nd Street, New York, N.Y.

APPLICATION FOR ASSOCIATE MEMBERSHIP

(Application forms for other grades of membership are obtainable from the Institute)

To the Board of Directors

Gentlemen:

I hereby make application for Associate membership in the Institute of Radio Engineers on the basis of my training and professional experience given herewith, and refer to the members named below who are personally familiar with my work.

I certify that the statements made in the record of my training and professional experience are correct, and agree if elected, that I will be governed by the constitution of the Institute as long as I continue a member. Furthermore I agree to promote the objects of the Institute so far as shall be in my power, and if my membership shall be discontinued will return my membership badge.

.....
(Sign with pen)

.....
(Address for mail)

....
(Date) **(City and State)**

Sponsors:

(Signature of references not required here)

Mr. ..... Mr. .....

Address ..... Address .....

City and State ..... City and State .....

Mr. .....

Address .....

City and State .....

The following extracts from the Constitution govern applications for admission to the Institute in the Associate grade:

ARTICLE II—MEMBERSHIP

Sec. 1: The membership of the Institute shall consist of: * * * (c) Associates, who shall be entitled to all the rights and privileges of the Institute except the right to hold any elective office specified in Article V. * * *

Sec. 4. An Associate shall be not less than twenty-one years of age and shall be a person who is interested in and connected with the study or application of radio science or the radio arts.

ARTICLE III—ADMISSION AND EXPULSIONS

Sec. 2: * * * Applicants shall give references to members of the Institute as follows: * * * for the grade of Associate, to three Fellows, Members, or Associates; * * * Each application for admission * * * shall embody a full record of the general technical education of the applicant and of his professional career.

ARTICLE IV—ENTRANCE FEE AND DUES

Sec. 1: * * * Entrance fee for the Associate grade of membership is $3.00 and annual dues are $6.00.

ENTRANCE FEE SHOULD ACCOMPANY APPLICATION

(Typewriting preferred in filling in this form) No.....

RECORD OF TRAINING AND PROFESSIONAL EXPERIENCE

Name .....
(Give full name, last name first)

Present Occupation .....
(Title and name of concern)

Business Address .....

Permanent Home Address .....

Place of Birth..... Date of Birth..... Age.....

Education .....

Degree .....
(college) (Date received)

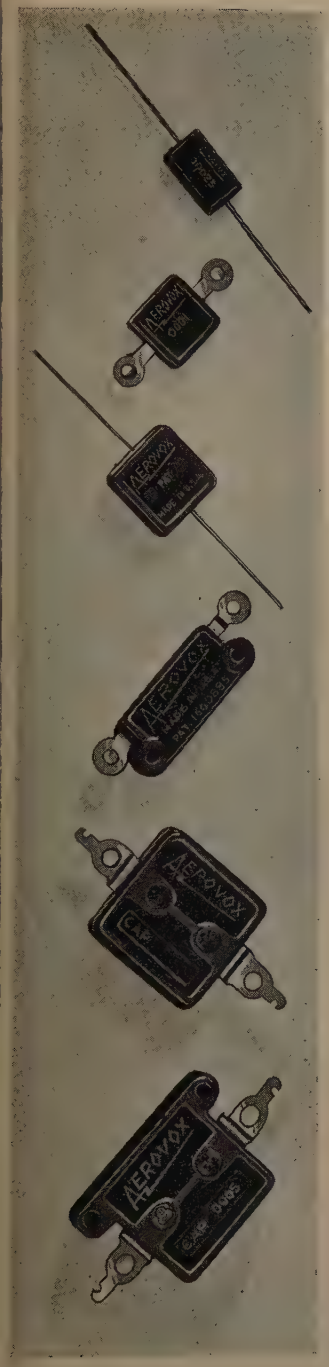
TRAINING AND PROFESSIONAL EXPERIENCE

DATES	

Record may be continued on other sheets of this size if space is insufficient.

Receipt Acknowledged..... Elected..... Deferred.....

Grade ..... Advised of Election..... . This Record Filed.....



Mica CONDENSERS

. . . *AEROVOX Engineered*

TINY units . . . low in price . . . made by the millions. Yet mica condensers are an important feature of *the complete* AEROVOX line of condensers and resistors. Indeed, our plant has its own mica department, bakelite molding equipment and mica engineering staff.

Thus AEROVOX mica condensers are fully on a par with all other AEROVOX products—likewise thoroughly engineered for satisfactory performance, likewise mass produced for lowest prices consistent with lasting quality. And the AEROVOX line includes the largest assortment of standard bakelite molded and metal cased units—twelve types to choose from.

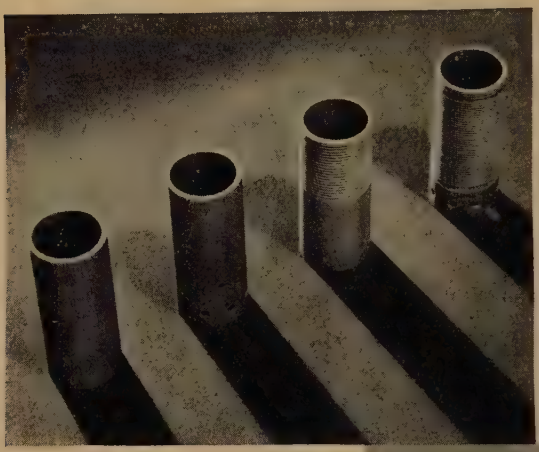
So simply specify AEROVOX mica condensers. That implies: Selected India ruby mica micrometrically calipered for uniform thickness and accurate capacity values. Best grade tinfoil. Sections thoroughly dehydrated and impregnated prior to molding in genuine Bakelite. Positive sealing and protection against temperature, moisture, chemical action and mechanical damage.

Send for DATA: New 1935 catalog covers *the complete* line of AEROVOX condensers and resistors. Also sample copy of monthly Research Worker. And do not hesitate to place your condensers and resistor problems before our engineers.

AEROVOX CORPORATION

71 Washington St. Brooklyn, N.Y.

When you come to Detroit . . .



You will find a warm welcome at the Synthane Show. While you are there make a point of looking over Grade XX Radioform tubing. Absolute uniformity, low power factor at radio frequences and extremely low moisture absorption are three advantages you will appreciate, particularly for short-wave coil forms where selectivity and sensitivity of tuned radio circuits are of first importance.

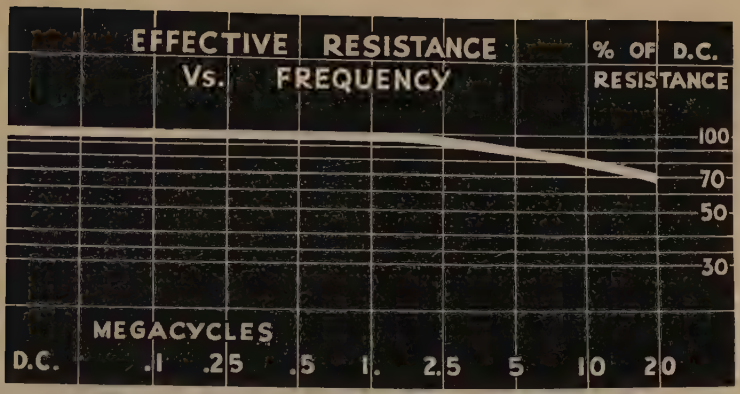
Examine SYNTHANE radio panels and fabricated parts as well . . . in Grade XX for high surface and volume resistivity, high dielectric strength and low power factor—Grade XP for difficult punching operations. Notice the clean cut holes and edges and the complete freedom from cracking or delamination . . . You will also be interested in the SYNTHOGRAPHIC PROCESS, our new low cost method for marking radio panels, or dials, or other parts fabricated in quantity from laminated bakelite.

SEE OUR DISPLAY
July 1, 2 and 3
AT DETROIT

SHEETS • RODS • TUBES
COIL FORMS • PANELS
FABRICATED PARTS
SYNTHOGRAPHIC PROCESS

SYNTHANE
CORPORATION OAKS · PENNA

SPECIFY SYNTHANE IN ORDERS TO YOUR SUPPLIERS



WHAT A HIGH FREQUENCY TEST SHOWS ABOUT RESISTORS

This chart based on an impartial test on standard 1.0 meg. Type "F" IRC Metallized Resistors tells its own story as to why these units are so generally specified for the exacting requirements of Short Wave oscillator circuits, AVC filter circuits, as grid leaks across r. f. tubes, etc.

. . . *Only a change of 30% in resistance value on 20 megacycles!* Compare this with resistance changes of over 75% on ordinary resistors under similar high frequency conditions and you have another of the important reasons why IRC'S are consistently specified by those who demand the best.

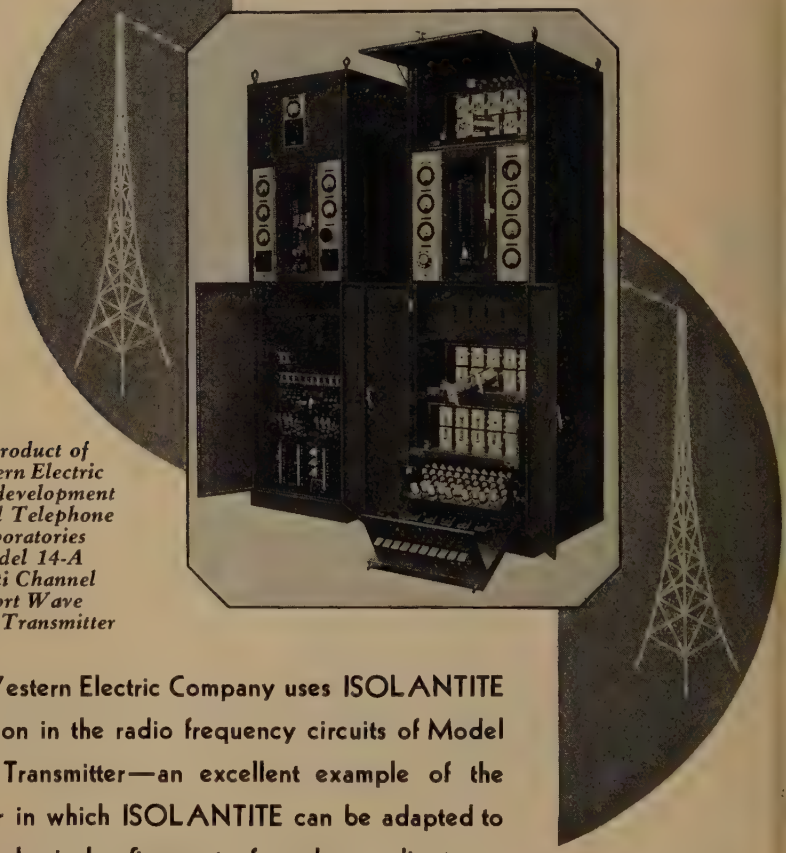
INTERNATIONAL RESISTANCE CO.

2100 Arch St., Philadelphia, Pa.

(In Canada, 187 Duchess St., Toronto, Ont.)

Metallized IRC RESISTORS

IMPROVE *your Equipment with* **Isolantite**



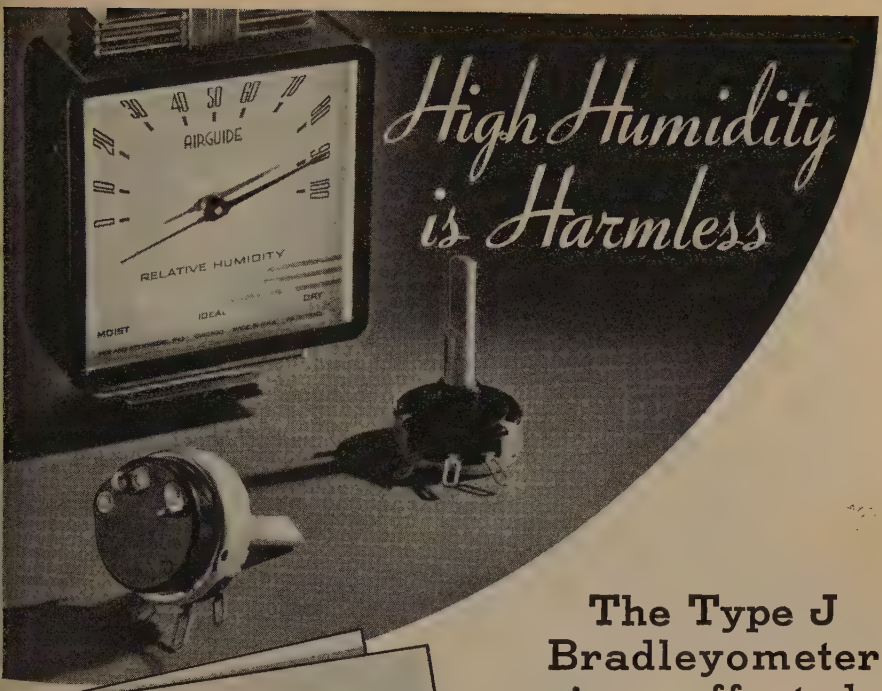
A product of Western Electric and a development of Bell Telephone Laboratories Model 14-A Multi Channel Short Wave Radio Transmitter

The Western Electric Company uses ISOLANTITE insulation in the radio frequency circuits of Model 14-A Transmitter—an excellent example of the manner in which ISOLANTITE can be adapted to the mechanical refinement of modern radio transmitters. *Your equipment can be improved with ISOLANTITE insulation.*

Isolantite Inc.

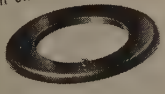
Factory at Belleville, N. J.

NEW YORK SALES OFFICE: 233 BROADWAY



High Humidity is Harmless

THE TYPE J BRADLEYOMETER
is made in two types; Type J is a volume control without line switch; Type JS with line switch. Both units are amazingly compact.



EASY TO MOUNT—Snapped into place on the panel with a C-washer. No threaded sleeves or nuts—no loosening.

A SOLID MOLDED RESISTOR —NOT A FILM-TYPE UNIT—
The Type J resistor is homogeneous—in longitudinal section the material is varied to suit specified resistance-rotation curves. After molding, hard service cannot alter its performance. Moisture does not deteriorate it. Practically any resistance-rotation curve shape can be provided including straight logarithmic, modified logarithmic, or linear.

The Type J Bradleyometer is unaffected by moisture

MOISTURE—the trouble maker for ordinary volume controls—cannot enter the *solid molded* resistor of the Type J Bradleyometer. Climatic variations pass unnoticed—long wear leaves no deteriorating effect on the remarkable resistor. Never before has such reliability been built into a volume control so compact. Its performance is so startling—its size so unique that the Type J Bradleyometer has set a new standard for modern volume controls.

Since the Types J and JS units are interchangeable with others built to R.M.A. standards, every radio receiver can now be improved with these dependable volume controls. Every radio engineer should have technical data on these units. Write today.

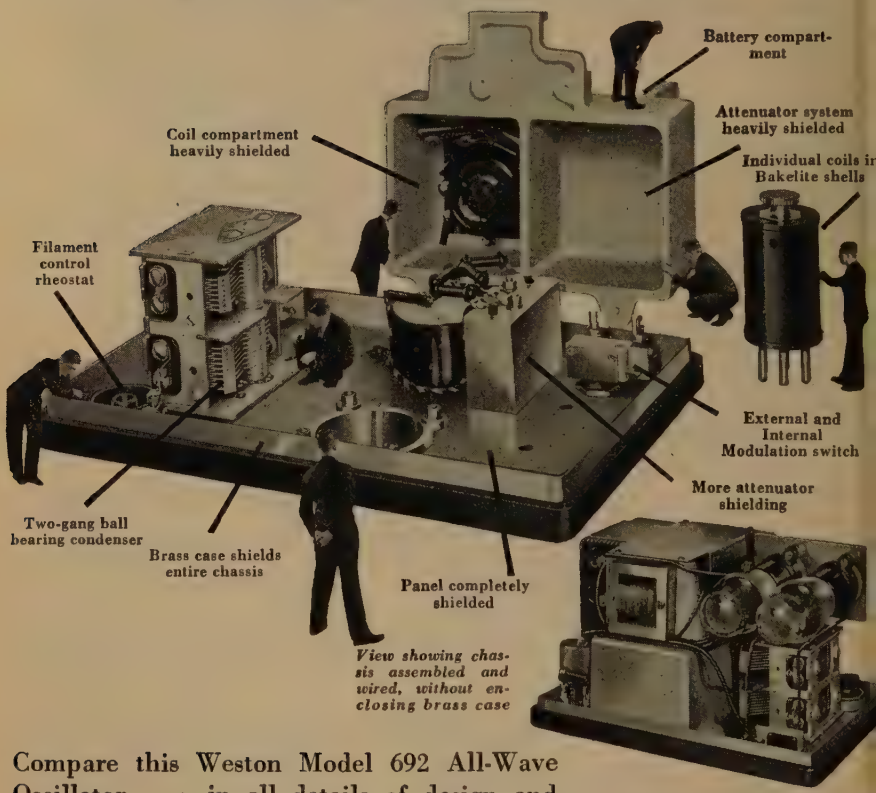
ALLEN-BRADLEY COMPANY
116 W. Greenfield Ave. Milwaukee, Wis.

■

ALLEN-BRADLEY RADIO RESISTORS

10 points of OSCILLATOR *difference*

OF VITAL INTEREST TO YOU!



View showing chassis assembled and wired, without enclosing brass case

Compare this Weston Model 692 All-Wave Oscillator . . . in all details of design and construction . . . part for part . . . with any the market affords. Note particularly that each part in Model 692 has been carefully designed for its special purpose. You'll agree that here is an oscillator you can safely stake your reputation on . . . that will enable you to do accurate servicing on all modern receivers. See Model 692 at your jobber's, or write for descriptive bulletin . . . Weston Electrical Instrument Corporation, 589 Frelinghuysen Avenue, Newark, New Jersey.

THE WESTON ALL-WAVE OSCILLATOR

NRA

WESTON *Radio Instruments*

When writing to advertisers mention of the PROCEEDINGS *will be mutually helpful.*

MORE THAN A *Million People* OWN OR OPERATE THE BELL SYSTEM

THE Bell System furnishes a nation-wide telephone service to a great and populous country—a service used for 59,000,000 talks a day. Telephone conversations per capita in this country are more than nine times as many as in Europe.

It takes 275,000 trained people to build and operate the switchboards, wires, cables, and other apparatus that make this service possible. It has taken the savings of 850,000 people to pay for the plant and equipment of the Bell System. Six hundred and seventy-five thousand own stock in the American Telephone and Telegraph Company, and in many instances other Bell securities. Another 175,000 own Bell System bonds or stock in the operating companies. No other business organization is so widely owned.

Since its beginning more than 50 years ago, the Bell System has rendered a constantly improving service more and more indispensable. Usefulness to the public is the motive that keeps the telephone business going. In the true sense of the word, this is a democracy in business.

BELL TELEPHONE SYSTEM

When writing to advertisers mention of the PROCEEDINGS *will be mutually helpful.*

CHIEF ENG'R.—
JUST RIGHT FOR OUR MIDGET AND AUTO RADIOS
PROD. MGR.—
NO MORE WORRYING ABOUT RESISTOR "SHORTS" IN SMALL SPACES
PURCH. AGENT—
AND THEY DON'T COST ANY MORE

They all endorse the new ERIE *Insulated* RESISTORS

From every angle the new Erie Insulated Carbon Resistors are meeting with enthusiastic praise.

In many cases engineering departments find that set design and operation can be improved by resistor relocation. The absolute protection offered by the ceramic shell removes all danger of "shorts" or "grounds" even in the smallest spaces.

Production departments like the improved method of color coding with bands completely encircling the insulating shell. The resistance value is easily read regardless of resistor position; and for the first time a practical method of signifying tolerance by the use of an additional color band is made possible.

Because Erie Insulated Resistors sell for the same price as non-insulated types, buyers are taking advantage of their exclusive features. If you haven't seen these new units, write for samples today.

ERIE RESISTOR CORPORATION

ERIE, PA.

***Factories in* ERIE, PA.-TORONTO, CANADA - LONDON, ENG.**

When writing to advertisers mention of the PROCEEDINGS *will be mutually helpful.*

The Institute of Radio Engineers

Incorporated

330 West 42nd Street, New York, N.Y.

APPLICATION FOR ASSOCIATE MEMBERSHIP

(Application forms for other grades of membership are obtainable from the Institute)

To the Board of Directors

Gentlemen:

I hereby make application for Associate membership in the Institute of Radio Engineers on the basis of my training and professional experience given herewith, and refer to the members named below who are personally familiar with my work.

I certify that the statements made in the record of my training and professional experience are correct, and agree if elected, that I will be governed by the constitution of the Institute as long as I continue a member. Furthermore I agree to promote the objects of the Institute so far as shall be in my power, and if my membership shall be discontinued will return my membership badge.

.....
(Sign with pen)

.....
(Address for mail)

....
(Date) **(City and State)**

Sponsors:

(Signature of references not required here)

Mr. ..... Mr. .....

Address ..... Address .....

City and State ..... City and State .....

Mr. .....

Address .....

City and State .....

The following extracts from the Constitution govern applications for admission to the Institute in the Associate grade:

ARTICLE II—MEMBERSHIP

Sec. 1: The membership of the Institute shall consist of: * * * (c) Associates, who shall be entitled to all the rights and privileges of the Institute except the right to hold any elective office specified in Article V. * * *

Sec. 4. An Associate shall be not less than twenty-one years of age and shall be a person who is interested in and connected with the study or application of radio science or the radio arts.

ARTICLE III—ADMISSION AND EXPULSIONS

Sec. 2: * * * Applicants shall give references to members of the Institute as follows: * * * for the grade of Associate, to three Fellows, Members, or Associates; * * * Each application for admission * * * shall embody a full record of the general technical education of the applicant and of his professional career.

ARTICLE IV—ENTRANCE FEE AND DUES

Sec. 1: * * * Entrance fee for the Associate grade of membership is $3.00 and annual dues are $6.00.

ENTRANCE FEE SHOULD ACCOMPANY APPLICATION

(Typewriting preferred in filling in this form) No.....

RECORD OF TRAINING AND PROFESSIONAL EXPERIENCE

Name .....
(Give full name, last name first)

Present Occupation .....
(Title and name of concern)

Business Address .....

Permanent Home Address .....

Place of Birth..... Date of Birth..... Age.....

Education .....

Degree .....
(college) (Date received)

TRAINING AND PROFESSIONAL EXPERIENCE

DATES	

Record may be continued on other sheets of this size if space is insufficient.

Receipt Acknowledged..... Elected..... Deferred.....

Grade ..... Advised of Election..... . This Record Filed.....

CORNELL-DUBILIER CONDENSERS

IN THE FOREFRONT OF THE FINEST

DEPENDABLE

as only the finest can be

Since 1910, C-D Products have consistently assured dependable performance, until today, condensers bearing the C-D label enjoy world-wide recognition second to none.

For performance in every field, industry is relying on C-D products because it knows to its satisfaction that . . . the C-D condenser is the "standard by which all other makes are measured."

Write for catalog No. 127 giving interesting engineering data.

CORNELL-DUBILIER
CORPORATION
4379 BRONX BOULEVARD • NEW YORK

N . 321

The TRIPLETT Decibel Meter

Measures Sound and Noise Levels

POWER Level Indicators are used to measure sound or noise levels in the amplifying systems of Public Address, Theater, Broadcasting Studio, etc. The Model 321 Decibel meter enables the operator to make immediate adjustments and keep the system free from distortion.

Furnished in two ways—either standard damped or highly damped, according to the particular need. Highly damped meters are generally used in Theaters, Broadcasting Studios and Public Address Systems. Standard damped meters may be used for Broadcasting Station equipment and special requirements.

The standard range furnished reads up 6 and down 10 decibels, zero decibels at 1.73 volts, 500 ohm line, 6 millivolts. Other ranges to order only. Meter furnished in Bakelite case.

See Your Jobber

THE TRIPLETT ELECTRICAL INSTRUMENT CO.

149 Main Street Bluffton, Ohio

MAIL TODAY FOR DETAILS

TRIPLETT ELECTRICAL INSTRUMENT CO.
149 Main St., Bluffton, Ohio

Gentlemen:

Please send me more information about Triplett Instruments. I am particularly interested in the No. 321 Decibel Meter.

Name .....

Street .....

Town ..... State .....

Metal-Can Electrolytics

For the largest line of round metal-can electrolytics . . .

●

For hermetic sealing, preventing loss or absorption of moisture

●

For all internal parts of aluminum, eliminating corrosion . . .

●

For special composition spacers, safety against surge voltages, no deterioration . . .

●

For longest service life, freedom from breakdown, economy first and last . . .

THREE years ago only one leading set manufacturer refused to use cardboard case electrolytics *at any price.* Today most manufacturers will have *nothing* but hermetically-sealed round metal-can units. As the pioneer in this field . . . as champion of the cause of sturdy, round metal-can, hermetically-sealed units . . . AEROVOX is gratified. Its engineering judgment stands confirmed.

Meanwhile, millions of AEROVOX round metal-can electrolytics serve daily in sets throughout the world. Performance backs original claims. Service life exceeds all expectations. Satisfaction, general. And all identified by the AEROVOX label.

Send for DATA: New 1935 Catalog just issued. Features *complete* AEROVOX Line of Condensers and Resistors. Also sample copy of monthly Research Worker. Meanwhile, call on our engineers for technical collaboration.

AEROVOX CORPORATION

71 Washington St. Brooklyn, N.Y.

PROFESSIONAL ENGINEERING DIRECTORY

BLILEY ELECTRIC CO.

Designers and Manufacturers
of
QUARTZ CRYSTALS
for
Standard or Special Requirements

Write for Catalog

230 Union Station Bldg.
ERIE, PENNA.

PRACTICAL RADIO ENGINEERING

One year Residence Course
Advanced Home Study Course
Combined Home Study-Residence Course

Write for details

Capitol Radio Engineering Institute
Washington, D.C.

Cathode Ray Tubes and Associated Equipment For All Purposes

Write for Complete Technical Data

ALLEN B. DUMONT LABORATORIES
UPPER MONTCLAIR, N.J.

FOR MANY YEARS

the Professional Engineering Directory has helped consulting engineers, designers, and laboratory men make the right contacts in the radio industry. Perhaps we can help you with your problems too. For further information write to

Advertising Department
INSTITUTE OF RADIO ENGINEERS
330 West 42nd Street
NEW YORK, N.Y.

Alphabetical Index to Advertisements

A

Allen-Bradley Company IX
Aerovox Corp. XVII
American Tel. & Tel. Co. XI

C

Central Radio Laboratories XX
Cornell-Dubilier Corp. XV

E

Erie Resistor Corp. XII

G

General Radio Co. ..... Inside Back Cover

I

International Resistance Co. XIX
I.R.E. ..... XIII, XIV, Inside Back Cover

P

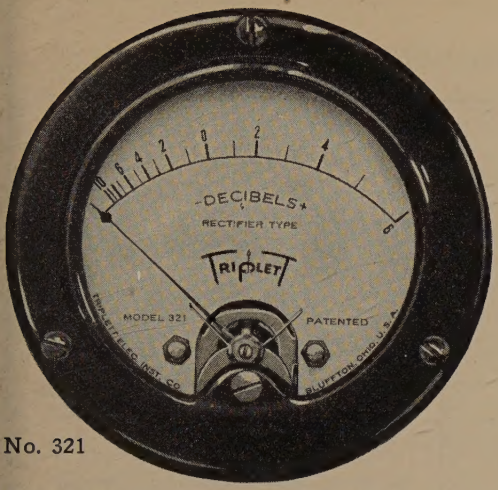
Professional Eng. Directory XVIII

T

Triplett Elec. Inst. Co. XVI

W

Weston Elect. Inst. Co. X



No. 321

The TRIPLETT Decibel Meter

Measures Sound and Noise Levels

POWER Level Indicators are used to measure sound or noise levels in the amplifying systems of Public Address, Theater, Broadcasting Studio, etc. The Model 321 Decibel meter enables the operator to make immediate adjustments and keep the system free from distortion.

Furnished in two ways—either standard dampened or highly dampened, according to the particular need. Highly dampened meters are generally used in Theaters, Broadcasting Studios and Public Address Systems. Standard dampened meters may be used for Broadcasting Station equipment and special requirements.

The standard range furnished reads up 6 and down 10 decibels, zero decibels at 1.73 volts, 500 ohm line, 6 millivolts. Other ranges to order only. Meter furnished in Bakelite case.

See Your Jobber

THE TRIPLETT ELECTRICAL INSTRUMENT CO.
158 Main Street **Bluffton, Ohio**

MAIL TODAY FOR DETAILS

TRIPLETT ELECTRICAL INSTRUMENT CO.
158 Main St., Bluffton, Ohio

Gentlemen:

Please send me more information about Triplett Instruments. I am particularly interested in the No. 321 Decibel Meter.

Name .....

Street .....

Town ..... State .....

PROFESSIONAL ENGINEERING DIRECTORY

BLILEY ELECTRIC CO.

Designers and Manufacturers
of
QUARTZ CRYSTALS
for
Standard or Special Requirements

Write for Catalog

230 Union Station Bldg.
ERIE, PENNA.

PRACTICAL RADIO ENGINEERING

One year Residence Course
Advanced Home Study Course
Combined Home Study-Residence Course

Write for details

Capitol Radio Engineering Institute
Washington, D.C.

Cathode Ray Tubes and Associated Equipment For All Purposes

Write for Complete Technical Data

ALLEN B. DUMONT LABORATORIES
UPPER MONTCLAIR, N.J.

FOR MANY YEARS

the Professional Engineering Directory has helped consulting engineers, designers, and laboratory men make the right contacts in the radio industry. Perhaps we can help you with your problems too. For further information write to

Advertising Department
INSTITUTE OF RADIO ENGINEERS
330 West 42nd Street
NEW YORK, N.Y.

Alphabetical Index to Advertisements

A

Aerovox Corp. XV
American Tel. & Tel. Co. VII

C

Central Radio Laboratories XXII
Cornell-Dubilier Corp. VIII

E

Erie Resistor Corp. XXI

G

General Radio Co. ..... Inside Back Cover

I

International Resistance Co. XVII
I.R.E. ..... XIII, XIV, Inside Back Cover
Isolantite Inc. XVIII

P

Professional Eng. Directory XX

R

R.C.A. Mfg. Co. ..... X, XI

S

Stackpole Carbon Co. IX
Synthane Corporation XVI

T

Triplett Elec. Inst. Co. XIX

W

Weston Elect. Inst. Co. XII

INSTITUTE SUPPLIES

EMBLEMS

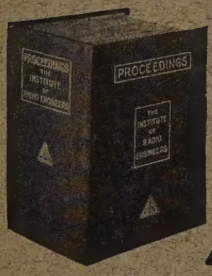
Three styles of emblems are available to members of the Institute only. They are all of 14k gold with gold lettering on an enameled background, the color of which indicates the grade of membership. The approximate size of each emblem is as illustrated.

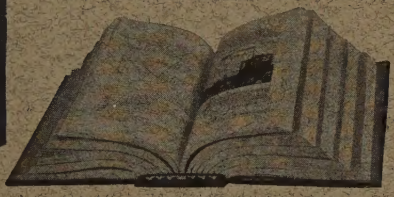
The lapel button is supplied with a screw back having jaws which fasten it securely to the coat. The price is $2.75, postpaid, for any grade.

The pin which is provided with a safety catch may be obtained for any grade for $3.00, postpaid.

The watch charm is handsomely finished on both sides and is equipped with a suspension ring for attaching to a watch chain or fob. Price for any grade, $5.00, postpaid.

BINDERS





Binders are available for those who desire to protect their copies of the PROCEEDINGS with stiff covers. Each binder will accommodate the twelve monthly issues published during the year. These binders are of blue Spanish Grain Fabricoid with gold lettering, and will serve either as temporary transfers or as permanent binders. They are so constructed that each individual copy of the PROCEEDINGS will lie flat when the pages are turned. Copies can be removed from the binder in a few seconds and are not damaged by their insertion. They are priced at $1.50 each, and the member's name or PROCEEDINGS Volume Number will be stamped upon the binder in gold for $0.50 additional.

BACK ISSUES OF THE PROCEEDINGS

Complete volumes of back issues of the PROCEEDINGS are available in unbound form for the years 1918, 1921, 1922, 1923, and 1926 at $6.75 per year (six issues). Also complete unbound for 1931, 1932, 1933, and 1934 at $7.50 per year. A list of the available miscellaneous copies published from 1913 on may be obtained from the Secretary. Single copies published prior to 1927 are sold to members at $1.13 each, and those issued during and after 1927 are $0.75 each. Foreign postage on single copies is $0.10 per copy, making $0.60 on unbound volumes before 1927.

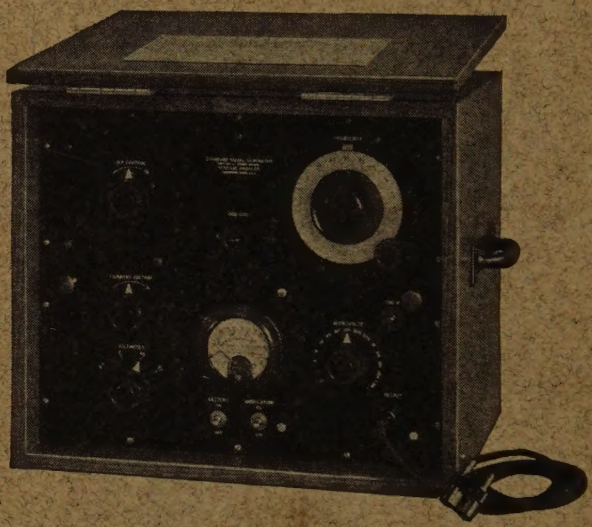
Issues for 1922 may be obtained bound in blue buckram at $8.75 per volume Similar bound volumes for 1930, 1931, 1932, 1933, and 1934 are priced at $9.50 each to members. Foreign postage is $1.00 additional per volume. Volumes for 1922 and 1926 bound in Morocco leather are available at $10.25 each to members volume for 1931 is $11.00.

TWENTY-TWO-YEAR INDEX

An Index of the PROCEEDINGS for the years 1909-1930, inclusive, is available at $1.00 per copy. It is extensively cross indexed. The earlier references are to the PROCEEDINGS of the Wireless Institute; the PROCEEDINGS of the Institute of Radio Engineers has been published since 1913.

When ordering any of the above, send remittance with order to the Secretary, Institute of Radio Engineers, 330 West 42nd Street, New York City.

MAINTENANCE AND PRODUCTION RECEIVER TESTING



FOR

Low Frequency Telephone and Telegraph
High-Frequency Broadcast
City and State Police
Standard Broadcast
Direction Finding
Fixed and Coastal
Broadcast Pick-up
Marine Fire
Television
Aircraft
Ship

RECEIVERS operating in the 100 to 6000 kc band, the General Radio Type 601-A Standard Signal Generator is in increasing demand.

An inexpensive, accurate standard-signal generator, with vacuum-tube internal modulation of good waveform and low-frequency modulation, this instrument merits your attention.

It may be the solution to your problem, as it has to that of many governmental and commercial agencies engaged in the design, development, routine and production testing of radio receivers. Its price: $210.00

May we send you further particulars? Ask for a copy of Catalog H-R.

TWENTY YEARS OF 1915 GR 1935 GENERAL RADIO COMPANY ELECTRICAL APPARATUS MANUFACTURE

GENERAL RADIO COMPANY

30 State Street Cambridge A, Mass.

GEORGE BANTA PUBLISHING COMPANY, MENASHA, WISCONSIN